PRODUCT REALIZATION AND LEAN MANUFACTURABILITY OF HOME DOCKING STATION

by
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ABSTRACT

DILLON COLT HALL: Product Realization and Lean Manufacturability of Home Docking Station

The focus of this research study was to analyze the product realization cycle, which is the process of creating, refining, manufacturing, and mass-producing a product that both fulfills customer needs and maximizes profit. This was done by utilizing the product realization life cycle to generate a product for potential customers in the University of Mississippi, city of Oxford, and Lafayette County area. The product to be researched was a home docking and organizational stand for a user's personal items like a phone, watch, keys, wallet, and other necessities. First, the conceptual design process was followed to develop customer needs and determine how these translate to product features and functionality. These requirements were then used to develop a draft product that could be manufactured with resources and equipment available to the Center of Manufacturing Excellence, an on-campus facility with a fully-equipped factory floor. Marketing and financial considerations were considered at each step of the design process and a best concept was refined to fulfill most, if not all, customer requirements. The second aspect of this research study was optimizing the product and its manufacturing process so that it could produce the maximum amount of profit with the least amount of waste or non-value-added activity and material while staying ahead of lead times required by simulated customer bases. Improvements were made as necessary to establish the best process flow and layout for the product.

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1 Introduction to Product Realization

Any new product introduced to the market experiences a developmental series of milestones that signify its progress towards satisfying original customer needs and the profit margins of the company supplying the product. The creation, development, marketing, and production of a quality product is revolved around these two concepts. Obviously, the bottom line for both the customer and the supplier relies on many factors within each stage of product realization, some potentially making the difference between a greatly received product with excellent return or a washout product with minimal profit margins. This thesis will delve into the complete life cycle of a sample product from its first conception as an identifiable need and its development into a completely realized product while elaborating on prototyping design considerations along the way. Then, this research will investigate the implications of lean manufacturing principles being applied to mass production processes and how these principles could affect the profit margins of a company while maintaining customer satisfaction. Examples of common mistakes and smart decisions made in the real-world market at each stage of product realization will be compared alongside the design choices made for the sample product as well.

Figure 1 outlines the steps of the entire product life cycle that this thesis will investigate individually, originally conceptualized in the textbook *Engineering Design* (Dieter & Schmidt, 2009). However, aspects of design and manufacturability will be evaluated on a concurrent design approach. This means that the impact of every decision made along this process will be evaluated with respect to every segment involved in the product's realization (design, marketing, manufacturing, financing, etc.). Instead of evaluating aspects of design only as they appear in the product life cycle, this approach predicts the influence of any early design decision on the rest of the design cycle and prevents a significant deficit of time or money from accumulating due to early design flaws.

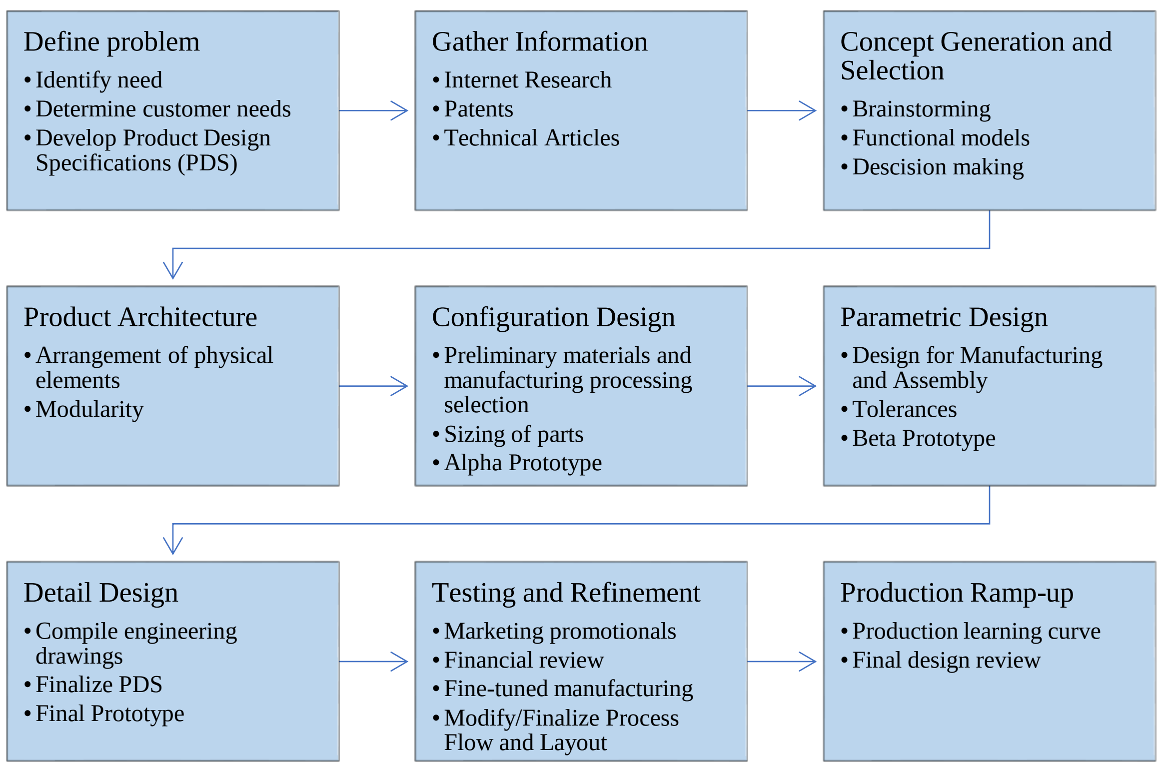

Figure 1 – Engineering Design Process

2 Design Development

This level of product realization involves the very beginning of the lifecycle, where the problem is defined, and is completed upon creating an initial prototype. Several milestones are completed within this level of the conceptual design process and are discussed in the following subsections.

2.1 Defining the Problem and Product Ideation

Every product begins with an idea that is a means to solve a problem of some variety or magnitude that may inconvenience the general consumer. The beginning of the product realization cycle is an identification of a need within a target market or recognizing areas in the community where quality of life could be improved. Design teams will use this identification to brainstorm means of fulfilling it. Simulating the beginning of this cycle within the scope of the sample product is done by devising needs within the University of Mississippi community and developing those needs into a definable problem. As seen by the design team, there was an apparent need observed from university student life, young professionals, and general Ole Miss fans for a product that could organize and/or charge common items that are typically carried on one’s person. Students that preferred a more organized setup of watches, keys, phone, wallet, and other necessities would find a product like this to help them excel in their day-to-day routine.

2.1.1 Determining Customer Requirements

With a problem statement established, it’s now necessary to establish customer requirements. These are a ranked listing of what the customers need and want from the product being designed. Generally, these relate to four fundamental measurements: performance, time, cost, and quality. Performance deals specifically with what the design should do; customers often value a product that operates or performs as it is intended. Time and cost are straightforward factors of customer requirements; however, quality can be somewhat complex, having many meanings and involving many aspects of the design. All of the customer requirements for the simulated product, dubbed the Dock of Champions, will be with respect to these four variables and will be important to translating them into engineering requirements, which design teams use to brainstorm concepts for the proposed product. In the case of the Dock of Champions, a limited survey was taken from students currently enrolled at the University of Mississippi and the University Special Events committee to determine what features or operations would be most valuable to the product. These customer requirements are listed by priority in Table 1.

Table 1 – Dock of Champions Customer Requirements

Priority	Requirement	Description
1	Compact	The product shouldn't take up too much space on whatever surface it occupies without being cluttered
2	Item Storage	Most, if not all, items usually carried on one's person must have a space to be stored on the docking station including: phone, smartwatch, wallet, keys, etc.
3	Cost	Must be considered a reasonable and affordable price for the quality of the product being made
4	Compatibility with Charging Chords	All retail charging cords for Apple® smartphones and smartwatches must be able to install into the station
5	Aesthetic	Station must offer some unique material, finish, and etching to add aesthetic appeal
6	Easy Assembly	Assembly of docking station should be tool-less, quick, and simple

These customer requirements are then converted to engineering requirements. This is done by taking the "what's" of the previous table and turning them into "how's." For example, consider the first customer requirement stating to make the product compact, so that it would fit within a small space. This could be with respect to surface area or volume, so a design team may try to minimize both while avoiding a cluttered station. From research done on existing products, the average size of a similar docking station is 12 inches long x 8 inches wide x 12 inches tall, so design concepts will attempt to lower these values to require less space. Table 2 converts the customer requirements given for the Dock of Champions into engineering requirements that help design teams conceptualize a product that would fulfill these customer needs.

Table 2 – Dock of Champions Engineering Requirements

	Requirement	Description
1	Volume	The product of the overall length, width, and height of the product, which correlates to total cubic inches of space taken
2	Placement surface area	The product of the length and width of the product, which relates to the total square inches of desk space taken by the product
3	Charging port diameter	Size in inches that the charging port will accommodate for
4	Material rigidity	Material must be strong enough to withstand the occasional ding or scratch and still look and operate nominally
5	Time to assemble	Length of time it takes for a customer to assemble product for use
6	Storage surface area	The square inches that is available to store personal belongings before becoming cluttered
7	Storable number of items	Number of personal items that could typically be stored on the product before it becomes cluttered

2.1.2 Creating the PDS

It is now appropriate to create a Product Design Specifications (PDS) table. This table is the basic control and reference document for the design and manufacture of the product for the rest of the product realization lifecycle. By creating the PDS, the customer needs and wants are finalized, prioritized, and cast into a technical framework so that design concepts can be established. The PDS explains as completely as possible what the product does without elaborating how the requirements are to be fulfilled with things like engineering specifications and design sketches. This will make clear what the customer wants and avoid hasty decision-making with undue assumptions about limitations, constraints, and design choices. The PDS helps design teams think on the same level as the customer and describes the desired product and its features in a fundamental sense.

Table 3 elaborates on the Product Design Specifications of the charging and organizing stand. This PDS starts by elaborating on the identifying aspects of the product, its special features, and its key performance targets. According to the table, the Dock of Champions is a means to store and organize common portable items and specializes in compatibility with multiple electronic devices. The marketing side of the product is explained in the identified market, financials, and legal requirement sections. These help the design team prioritize features that would be important to the intended user and solidify budget and legal constraints that might be present. Lastly, manufacturing specifications detail what process or logistical restraints may be existent. In the case of the sample product, the only manufacturing constraint involved is location.

Table 3 – Product Design Specifications for Dock of Champions

Product Identification

- Tabletop docking station that neatly organizes common portable items carried on one's person
- Can store and charge any cellular device and Apple Watch®
- Compact design that can fit on any nightstand or work surface

Special Features

- Compatible with any charging cable and Apple Watch® pod
- Sophisticated design and finish

Service Environment

- Indoor Use
- Up to 100% humidity

Key Project Deadlines

- Four months to finalize product design
- Four months to complete manufacturing process design

Physical Description

- Approximately 5 inches wide, 10 inches long, and 10 inches tall
- Material: Cherry wood
- Features to house phone and watch charging cables
- Various pockets and pegs to house other portable items

Market Identification

- Target market: University Special Events, students, young professionals, and Ole Miss fans
- Initial Launch: Oxford, MS and surrounding area
- Competing products vary but require more space and store less items
- Initial production: 1000 units

Financial Requirements

- Target manufacturing cost: $25
- Estimated Retail Price: $40
- Warranty Policy: limited lifetime warranty

Life Cycle Targets

- Useful for at least 5 years
- Minimal maintenance required
- End of life strategy – can be recycled as available to the user

Social, Political, and Legal Requirements

- Safety regulations will be followed
- Existing patents will be investigated
- Minimal liability risks

Manufacturing Specifications

- Everything constructed on Center for Manufacturing Excellence factory floor
- Suppliers: TBD

2.1.3 Initial Research

The first step into making the specifications listed before into a real product, a design team needs to gather as much information on the proposed idea as possible.

Preliminary research is crucial to discover existing products on the market, determine limitations on designs, and become aware of any constraints to the product that were not stated on the PDS. Useful resources include but are not limited to: patent files, technical articles, trade journals, product-specific consultants, and internet sources. Patent files, not only show design teams what existing products are on the market, but also detail what features and designs would require legal permission to reproduce. Technical articles, magazines, and newsletters related to the product typically contain a plethora of information on creating the product entirely or on how to make specific features that may initially seem too complex or impossible to make. Consulting with a specialist in the market that the product is intended could prove very beneficial, as he or she may have good information as to what features and design choices may be most valuable to the intended market. Specialists in design and manufacturing would also be helpful in determining what design features are feasible to make in a typical machine shop or would require complex equipment.

Searching internet sources reveals multiple ideas that could be used for concept generation. Figure 2 shows some existing products that are already available on the market. The NytStnd TRAY 4 is a product that emphasizes aesthetic appeal and functionality, while attempting to find a middle ground for spaciousness and compactness (NytStnd, 2017). The Men's Monogrammed Docking Station by HD Crafts is unique in that it provides much more affordability than the NytStnd but also conceals ugly charging cables and includes more space to dock more unique items like a shot glass and small whiskey bottle (HDCraftsByHarry, 2018). These products are useful because they allow a design team to take concepts that customers are already familiar with and develop them to better satisfy the customer needs presented to them. Product reviews submitted by customers for these products are also invaluable information to design teams that want to improve on existing designs like these. The Dock of Champions will generally be created as if it were a new product invention but may include features from these products that were received well by users. This will put the docking station above the curve early in the design process, as the design concepts can be further refined to better satisfy customer needs in comparison to potential competitors.

Figure 2 – Existing Docking Station Products: a) NytStnd TRAY 4 Docking Station b) HD Crafts Monogrammed Men's Docking Station

2.2 Concept Generation

Figure 3 describes the sub-process of concept generation and evaluation that will be followed for the sample product. It describes the process for creating design ideas and, more importantly, determining which concept fulfills the most customer requirements and/or most satisfactorily fulfills all the customer requirements.

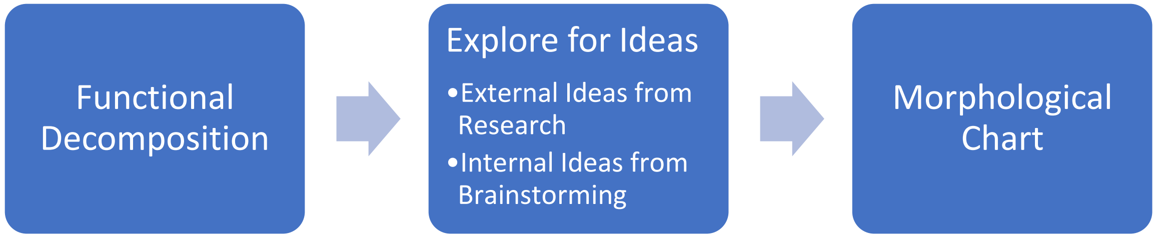

Figure 3 – Concept Generation Process Chart

2.2.1 Problem Decomposition

Before providing means of solving the functions required of a product, the functions themselves must be clearly identified. When this is done, a complete list of functions, sorted by priority, are created that help design teams synthesize ideas to fulfill them. These product functions typically encompass main features at an appropriate level of generalization, however, ideally include no more than ten functions. It is important to list the generalized functions and not assume any components. For example, a function of the Dock of Champions would be 'aesthetic appeal' as opposed to 'glazed wood composition.' Table 4 describes the functional decomposition of the Dock of Champions.

Table 4 – Functional Decomposition of Dock of Champions

PRIORITY	FUNCTION
1	Compactness
2	Item Storage
3	Charger Compatibility
4	Rigidity
5	Assembly
6	Aesthetic Appeal

2.2.2 Explore for Ideas

This portion of concept generation focuses on the 'means' of fulfilling the functions listed previously and is based mostly in generating innovative ideas from brainstorming or in retrieving information from initial research. The goal is not yet to decide a solution or narrow down ideas to the best concept, but to determine how many options are available to fulfill each of the functions demanded from the product.

Starting with the highest priority function, the compactness, or ability to take up minimal space, could be fulfilled through a variety of options. One option would be to design the product to utilize more vertical space. This would minimize surface area required by the product and allow for a unique shape. Yet another option could be to maximize surface area and minimize height. In this case, vertical space taken would be small. Optimization of the two previous ideas is also an option, where the smallest amount of surface area and volume are taken and a ‘happy medium’ was found.

Item storage is just as important as compactness, simply because the product would be ineffective if it could not fit everything that a consumer would want to store on the docking station. Options to fulfill this requirement include creating a cube-shaped product, which offers a significant amount of surface area to store items of various size. Utilizing vertical space is also an alternative that would allow for more items to be stored. Similarly, a dock that utilized more surface area would also have much more room for storing various items.

The product could also fulfill charger compatibility through a variety of options. One of these is to design the charging port to allow all charging cable inputs to fit through the port, meaning that the port would be sized for the largest sized charging cable input researched by the design team. Another idea would be to design the port as a slot where charging cables would be constrained to the docking station. Designing would be simpler in that the diameter of the charging cables varies little as opposed to the charging cable inputs.

Rigidity is a simple requirement to fill, in that a material of high tensile strength could be chosen to ensure that the product has a low risk of fracturing, breaking, or bending. Options would include steel, various hardwoods, high strength polymers, and more. Certain geometries of the product would lend itself to higher rigidity. For example, a shorter and more compact design may have more stiffness and/or fracturing resistance than a product that is like a long board.

Assembly options can range based on simplicity and strength of the constrained pieces. On one end of the spectrum, products made from minimal parts and loosely mated through a partially constrained slot joint would provide a much simpler means of assembly. On the other hand, the product could be assembled through screws and epoxy. This would ensure a clean and tight bond between all parts of the assembled product.

Continuing from the example in Section 2.2.1, the Dock of Champions may fulfill the aesthetic appeal function through glazed wood, brushed metal, 3D-printed plastic, or other types of finished material. Etchings are also available as an option for added cosmetics, dependent on the customer's preference.

2.2.3 Morphological Chart

A morphological chart is a visual aid that captures the functional requirements of the product, lists all available options for achieving that functionality, and enables multiple concepts to be generated based on the various combinations of solutions possible for the product. A starting point for this chart is to establish the functions of the product. For this analysis, the functional decomposition list from Table 4 (Section 2.2.1) will be the basis for the solution options generated. The solutions are the means to fulfilling a function and many of these solutions to a function may be already known, but others could be new ideas conceived by the design team. From this chart, the most functional concepts, called principle solutions, are found and considered for evaluation as the best concept.

Table 5 describes the morphological chart used for concept generation of the Dock of Champions and lists three preferred combinations made from this chart. Functions are listed in the first column, available component options are in the next three columns, and the component options selected for each "principle solution" are shown in the last three columns. A principle solution is merely a combination of component options selected which will later be conceptualized into a visual design and evaluated based on customer needs by priority. The chart shows that for some functional criteria, one solution was favored for both principle solutions over other component options. This is perfectly acceptable, as it is makes clear that one design element has an initial functional advantage with demand to be utilized. With these principle solutions, a design team can begin with concept evaluation to determine which of these concepts would satisfy both customer needs while maximizing profit. It is important to note that the principle concepts in themselves are not compared here, only the design concepts for each function. Later in the concept evaluation process, whole design concepts will be compared with one another.

Table 5 – Morphological Chart for Dock of Champions Concept Generation

Function	Options			Principle Solution #1	Principle Solution #2	Principle Solution #3
Compactness	Utilize vertical space	Utilize surface area	Utilize both, find happy medium	Utilize surface area	Utilize both; find happy medium	Utilize vertical space
Item Storage	Cube-shaped	Totem-shaped	Cantilever-shaped	Cantilever shaped	Cantilever shaped	Cube Shaped
Charger Compatibility	Size for universal chargers	Charging wire slot	Size for specific phone and watch	Charging wire slot	Size for universal chargers	Size for specific phone and watch
Rigidity	Longer design; soft material	Longer design; hard material	Shorter design; hard material	Longer design; soft material	Shorter design; hard material	Shorter design; soft hard material
Assembly	Screws and Nuts	Glue	Slide-fitting	Slide-fitting	Slide-fitting	Screws and Nuts
Aesthetic Appeal	Glazed wood; Laser-etched logo	Natural wood	3D-printed plastic	3D-printed plastic	Glazed wood; Laser-etched logo	Natural wood

2.3 Concept Evaluation

The most effective way to evaluate competing concepts is to develop a Pugh chart. This is a particularly useful comparison technique for identifying the most promising design concept among the alternatives generated. A Pugh chart functions by comparing each concept relative to a reference or datum concept and determines for each defining criterion whether an alternative concept is better than, poorer than, or about the same as the reference concept. The following subsections detail the steps for creating and using a Pugh chart to determine the best concept.

2.3.1 Defining Criteria

The basis for which the reference and alternative concept will be evaluated must be established so that a comparison can be made. The Pugh chart for this design process will assess the concepts from the same functions defined in the morphological chart plus other important and relevant criteria like cost, weight, and portability. Additionally, these design criteria will be prioritized by a weight multiplier. By doing this, the comparison of higher priority functions will play the biggest factor in determining the best concept. This weight multiplier was determined by surveying a small sample of UM students that expressed interest in the product being developed. Each survey participant was given the list of criteria developed from functional decomposition with the addition of cost. Participants were also given 10 credits to distribute to each of the functions given to them. For example, if compactness was considered valuable, then a number of those credits would be given to that function based on how important the function was to each participant. If a function was not considered that valuable at all when compared to others, it would not receive any credits. The total amount of credits per function were then averaged to determine what function was considered the priority and by how much. The average amount of credits was then considered the multiplier to be applied for Pugh Chart analysis. Other additional criteria were not relevant to the functional requirements of the product, like cost, but still carry some pull as to how valuable the entire concept would be to a customer. These criteria for the Pugh chart are listed in Table 6 along with their respective weight multiplier.

Table 6 – Pugh Chart Comparative Criteria

PRIORITY WEIGHT	FUNCTION
2	Compactness
2.5	Item Storage
1.8	Charger Compatibility
1.2	Rigidity
1.4	Ease of Assembly
3	Aesthetic Appeal
2.4	Cost
1.8	Ease of Use
1	Portability

2.3.2 Clarify Design Concepts and Choose Datum Concept

Now, a design team must develop sample drawings of the concepts to be compared and choose which one will be the datum concept of the Pugh chart. Figure 4 displays sample concepts developed using Creo Parametric modeling software. The emphasis of these concepts is to create the minimum number of features and dimensions required besides those chosen from the morphological chart, and not to distinguish specific dimensions and manufacturing features. These samples are used solely to help visualize the concepts for comparison to one another.

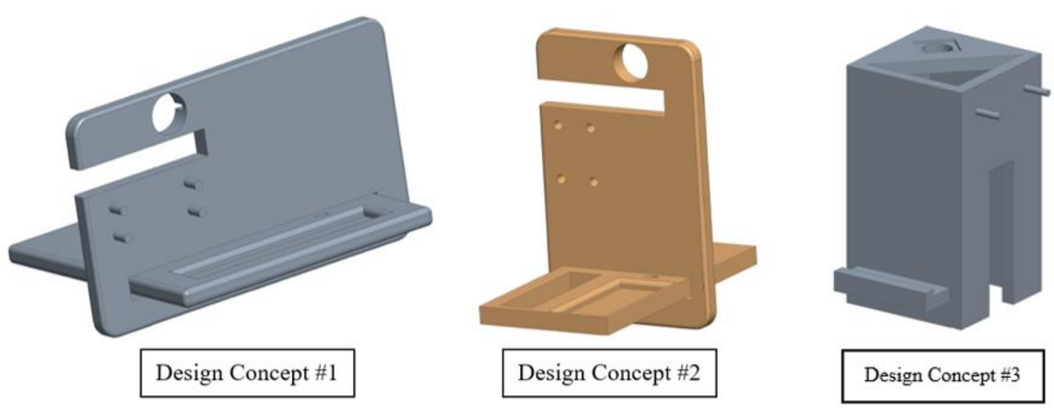

Figure 4 – Pugh Chart Design Concept Drawings

A datum concept must be chosen to compare to the other design concept available. There is no definite criterion for determining the best datum concept, simply because the best concept will show itself through the way it scores on the Pugh chart. If the alternative concept proves itself as fulfilling more of what customers require, then the competitive nature of the Pugh chart will lead that concept score higher. Therefore, the datum concept can be chosen at random. For this analysis, Design Concept #1 will be evaluated first as the datum concept.

2.3.3 Populate Decision Matrix and Evaluate Ratings

Table 7 shows the completed Pugh chart, comparing Design Concept #2 and #3 to Design Concept #1, which is treated as the datum concept. To complete the Pugh Chart, the alternative design concepts are evaluated with respect to each function as performing better, worse, or the same as the datum concept, represented by a score of pluses (+), minuses (–), and zeros (0). The number of pluses or minuses corresponds to how much better or worse the alternative concepts are to the datum concept. For example, Design Concept #2 was considered much more effective for compactness than the datum concept, and so two plusses were credited to that design for that design criterion. After the alternative design concepts have been scored, the weight given to each function is multiplied by the score given for that criterion, then the total amount of pluses, minuses, and zeros are totaled at the bottom of the chart. For the datum concept, all criteria would be given zeros, resulting in a total score of 0. For each alternative concept, the difference of the pluses and minuses would be taken to determine a net score with respect to the datum concept. A positive or negative net score corresponds to the product fulfilling more or less of the functional and customer requirements than the datum concept. According to the Pugh chart, Design Concept #2 scored higher than the datum score, which means that this alternative design more fully meets the design criteria set for this product. The chart also shows that Design Concept #3 scored only slightly higher in comparison to the datum concept, thus it should not be chosen as the best concept to use moving forward. From this information, it can be discerned that between all the design concepts, Design Concept #2 has shown to more likely satisfy most, if not all, of the customers' needs, if for only a slightly higher cost than Design Concept #1.

Table 7 – Pugh Chart Concept Evaluation for Dock of Champions

Design Criteria	Weight	Design Concept #1	Design Concept #2	Design Concept #3
Compactness	2	*D*	++	+
Item Storage	2.5	*A*	0	0
Charger Compatibility	1.8	*T*	+	0
Rigidity	1.2	*U*	0	0
Assembly	1.4	*M*	0	-
Aesthetic Appeal	3	*	+	+
Cost	2.4	*	-	-
Ease of Use	1.8	*	0	0
Portability	1	*	+	-
	+	0	9.8	5
	-	0	2.4	4.8
	Total	**0**	**7.4**	**0.2**

2.3.4 Best Concept

The results of the Pugh chart show that Design Concept #2 fulfills the most amount of functional and customer requirements. The conceptual design process from this point on will consist of fine tuning the selected design concept into a product with clearly defined dimensions and features, specific manufacturing methods, and straightforward costing to determine selling prices and profits gained per product sold.

2.4 Product Architecture

Now that a design concept has been realized, a design team must now start considering more specific aspects of the product design such as element arrangement. This plays in a larger part of the conceptual design process called product architecture. In this phase, the existence and position of features on the product will be finalized.

2.4.1 Arrangement of Physical Elements

The architecture of the design, or the arrangement of its physical elements, is a critical aspect of design to confirm first, mainly because the way that a product's features are arranged are parent aspects to the specific dimensions relating features to one another. To confirm the product's architecture, a design team must first compile all features that are to be included in or on the product. For the case of the Dock of Champions, it may be helpful to go a step further and grasp what the docking station will be caring in order to better understand the features that it would require. As a standard for the rest of the design process, the Dock of Champions is to be designed to hold a standard-sized smartphone, an Apple Watch® of any series or size, one additional watch, a pair of glasses, a reasonably sized set of keys, a wallet, and small pocket items like change or a tube of lip balm. An iPhone X with a protective case will be considered a "standard-sized" smartphone. The charging cables for both the smartphone and smartwatch will also be installed into the product upon assembly and the features to house them must be considered in the product's architecture. All of these items come to a total of nine features to house each item. This number can be reduced slightly by having the smartwatch and additional analog watch share the same feature, which brings the total features down to eight.

Each feature must have a certain functionality which will hold and constrain its designated item to the docking station, but also allow for easy removal. The smartphone, being the biggest of the items to be stored, is prioritized first. Using the cantilever-style design chosen from concept evaluation in Figure 4, it seems reasonable to position the smartphone so that it rests on top of the cantilever and leans against the face of the wall. The “feature” constraining the smartphone would be the surface area of the wall and cantilever that the smartphone covers. Placing the smartphone here would also coincidentally mark the position of the charging cable port as the point on the cantilever where the phone’s charging port would be placed. A sleek design involving cables generally hides all wires and directs them to the back of the product so that they are easier to plug in to wall outlets. Therefore, the cable will be directed as such by creating a mouse-hole feature at the bottom of the wall (or the fulcrum of the product). This feature is highlighted in Figure 5.

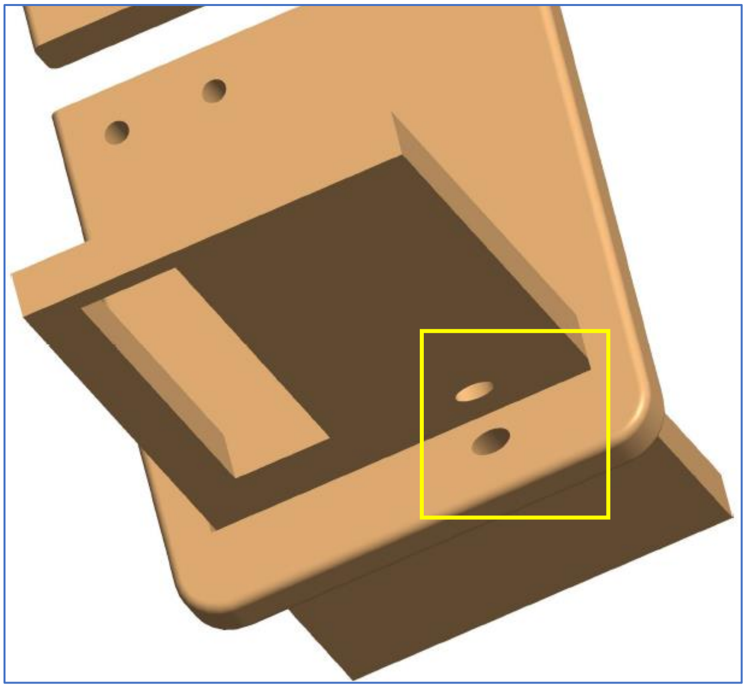

Figure 5 – Mouse-hole Feature for Smartphone Charging Cable

The next most important feature is that which will hold the watches and house the charging pod for the smartwatch. As was mildly detailed in the evaluation process, this feature will consist of an arm which will be formed by cutting a slot through the upper portion of the wall, allowing for watches to hang neatly from the wall. The slot will be milled wide enough so that watches can be added and removed with ease. The lower portion of the wall is used to hold the smartphone, as detailed previously, so dimensional considerations later must account for the amount of wall space needed for both of these features. The charging pod will show itself through the watch arm, but the cable pathway will be designed to be concealed in the back of the wall like the phone charging cable. This is necessary to accommodate a sleeker design that hides ugly and jumbled charging cables. Figure 6 shows the first design of the watch arm and a slot which will constrain the watch charging cable to the charging station.

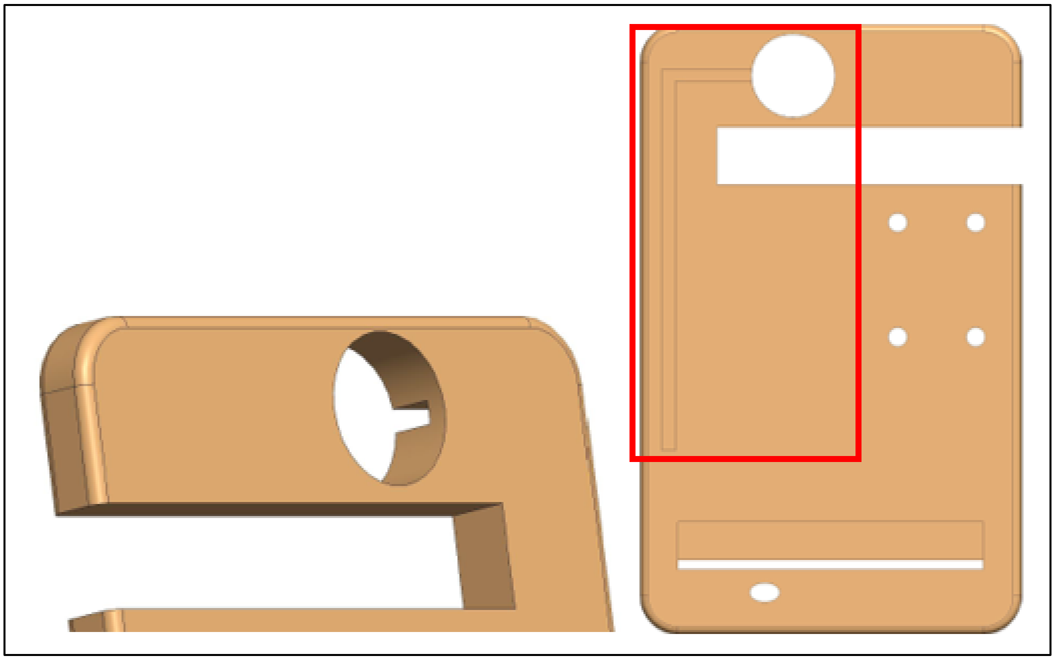

Figure 6 – Watch Arm (Front View) and Smartwatch Charging Cable Slot (Back View)

The next features to consider are those that will hold a set of keys and a pair of glasses. Both of these items can be constrained loosely with a peg from which the items will hang. Therefore, the two items are considered together with the same feature here. A peg in itself does not require much surface area or volume to add to a design, however, the area covered by the object hanging from it will be the main constraint to this feature. Therefore, this feature will be added to the wall of the product next. A set of four pegs will be initially included: two to constrain a pair of glasses, and two to constrain two sets of keys or other small looped items. This product feature is detailed in Figure 7.

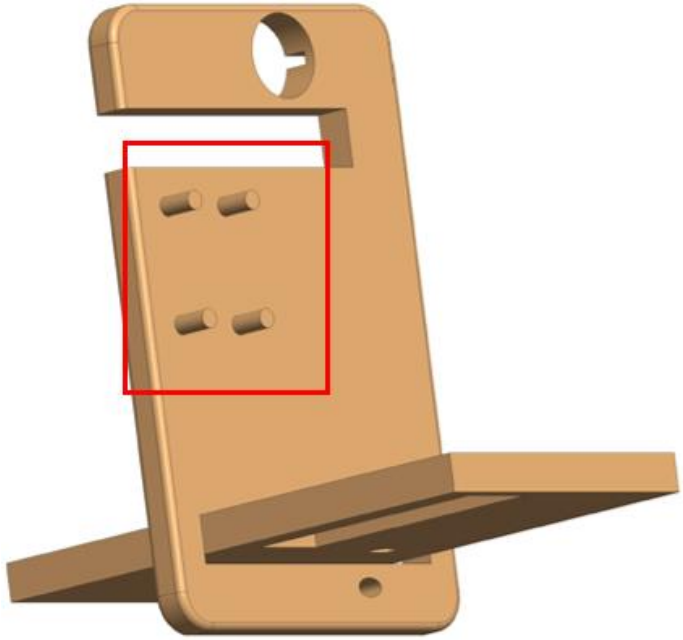

Figure 7 – Hanging Peg Feature

Now that the surface area of the wall has been fully utilized, the remaining features will be implemented to the cantilever. This includes the feature for the wallet and any small miscellaneous items. Since the docking station will be so low to the surface on which it is placed, the space below the cantilever will be utilized to store the wallet by adding a slot through the cantilever. This will have the wallet constrained by the desk or table surface and the sides of the slot. The slot will be sized appropriately later on to fit most sized wallets. The remaining forward surface area of the cantilever area will be used to house miscellaneous items. These types of items can vary greatly, from loose change and lip balm to a small pocket knife. Therefore, a pocket feature will utilize the remaining cantilever area to accommodate for items of various sizes and geometries. This pocket will extend up to the wallet slot and smartphone charging port, as shown in Figure 8.

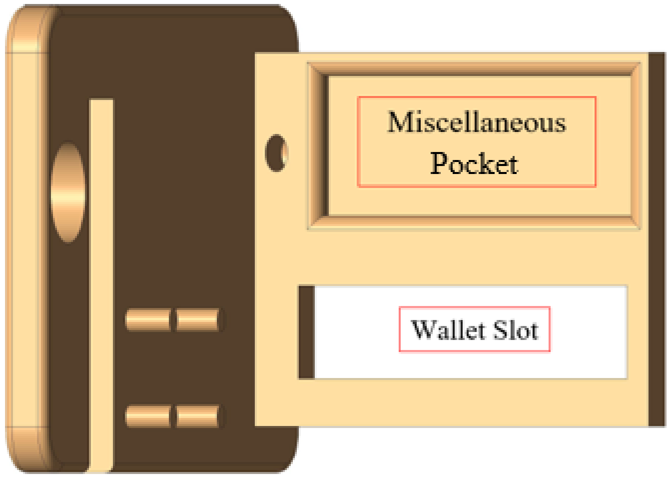

Figure 8 – Cantilever Wallet Slot and Miscellaneous Pocket

2.5 Configuration Design (Alpha Prototype)

The next phase involves much more specific criteria for design. This involves a preliminary selection of materials that will make up the product and determining the manufacturing processes which will be used to create it. Feature and part sizing will be done here as well to specify the scaling and dimensional aspects of the design.

2.5.1 Preliminary Materials Selection

Before researching and selecting material, a design team must first see to determining what kinds of materials will be needed. As determined during the concept selection phase, the design concept will use wood material and implement a laser-etched logo if profit margins allow for it. The docking station is a simpler design, in that it consists of two pieces of wood of similar widths and identical thickness loosely fitted together with four press-fitted lengths of small dowel rod. As per the aesthetic functional component of the original design concept, the product will consist of a clear coat glaze with a laser-etched logo. Altogether, there are three material components to be selected: wood planks for the cantilever and wall pieces of the product, dowel rods for the pegs, and glaze to finish the product.

Ideally, the wood planks would be bought pre-cut to the dimensions of the two pieces to reduce machining time, but this is normally not available with most lumber suppliers and, even if it were available, a premium would be charged for pieces to specific dimensions. The most efficient selections of wood planks are those that most closely resemble the dimensions of the parts being made. The docking station is to be compact in size while also thin in thickness, therefore a board 5-7” in width and about ½” in thickness is a good starting point for material research. Another important note is that just about any type of wood would be functionally feasible for the means of an indoor docking station where there are no heavy loads or extreme weather conditions to factor in. Therefore, the only constraining factors of wood plank material is cost per plank and aesthetic appeal. The wooden dowels which would make the pegs for the docking station are ruled by the same criteria and must match the wood type of the wood planks. The dowels will also be of small diameter so a good range to select from is 3/16”-1/4”. Wood-finishing options are numerous, from a clear glaze to a dark wood stain. A small can of stain can also be applied to a large number of parts, therefore the amount of stain bought is almost negligible as one pint of stain will be more than enough for all simulated processing. The only real constraint for this product outside of price is the desired finish from the customer.

Upon researching local and online lumber suppliers, the following materials for wood planks and dowels were found, as shown in Table 8. To reduce waste, the most cost-effective options for each material were selected for preliminary selection and prototyping. This includes the sande plywood sheets for wood planks and dowels made from basswood.

This also meant selecting no glaze or wood stain, since finishing operations are considered wasteful until an alpha prototype with minimal cost is considered profitable. Upon successful prototyping, costing analysis will be conducted to prove the financial advantage of swapping to potentially more expensive material and adding finishing operations.

Table 8 –Material and Supplier Information

Material Name	Material Description	Vendor	Price Per
Wood Planks			
Sande Plywood	1/2" X 4' X 8'	Home Depot	$31.95
Cherry Wood	1/2" X 5" X 48"	Rockler	$29.99
Dowels			
Basswood Dowel	1/4" X 48"	Home Depot	$0.86
Cherry Dowels	1/4" x 36"	Amazon	$8.02
Glaze			
Red Mahogany Wood Stain	8 oz.	Home Depot	$2.47
Krylon Clear Glaze	12 oz.	Amazon	$4.28

2.5.2 Initial Manufacturing Processing

The facility in which the product will be made could be a critically limiting factor to constructing the product as desired and the machines and equipment available could potentially constrain the features that can be made at all. For this reason, it is crucial to ensure the proper facilities and equipment are available to fabricate the entire product as intended. The docking station will be constructed in the Center for Manufacturing Excellence (CME) at the University of Mississippi. The CME facility contains a full inventory of state of the art manual and automated machines and tools and houses three fully-trained and capable technicians that can operate all the machines. This section will describe the initial manufacturing plans that will be executed in the CME facility and give a brief overview of the benefits and consequences of each machine selected in the process.

The first machining process to be done is to cut the stock wood material to the size of the two pieces used per product. In the case of the docking station, the wall and cantilever pieces will initially be sized as 5” and 4” pieces wide, respectively, and 8” long. To minimize cutting time, a higher feed rate is ideal, along with a form of guideway or constraint to ensure the blank pieces are cut straight every time. For this reason, a vertical panel saw, like the one shown in Figure 9a, will be used to cut the 4’x8’ plywood sheet into planks 5” wide by 48” long as shown in Figure 9b. This way, the wall piece is already cut to the correct size. Further processing done later will cut the 4” cantilever piece from this plank.

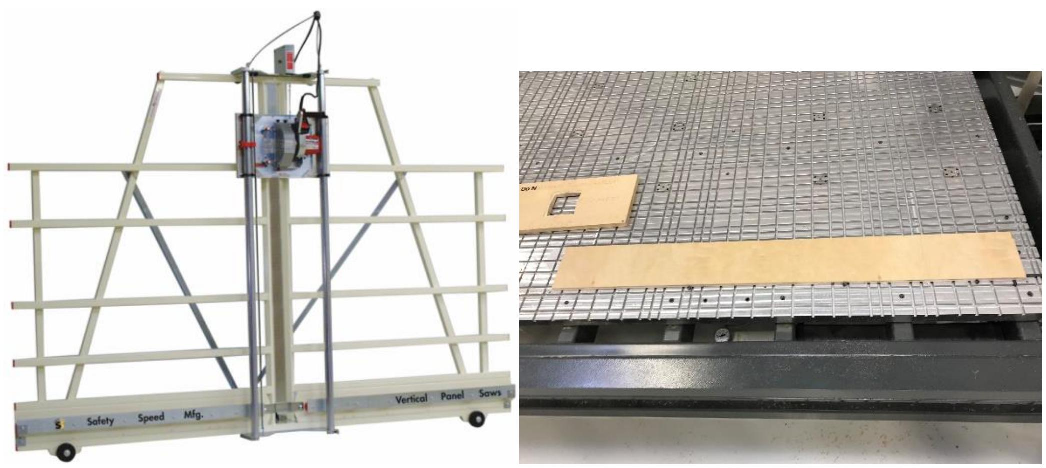

Figure 9 – a) Vertical Panel Saw and b) Post-Machined Plank

At this point, there are several 5”x48” planks. If the length of each piece of the docking station is 8” and there are two pieces total per docking station, then that means 16” of material is needed per product. Dividing this into 48” and rounding down to the highest whole number shows that a total of 2 products can be made per 48” plank. Therefore, a simple cut will be made with a vertical band saw, as shown in Figure 10, through the middle of the plank to product the blanks for a single product. This process allows for a lean process flow for all future steps because it eliminates batching. Batching occurs when more than one part is made from a single operation, meaning every part is part of a batched set. This leads to unnecessary wait times, as no part in a batched set can move forward in the production process until the whole batch is machined. A more ideal flow involves a continual cycle of running one part at a time for each step in the process, removing it, and then preparing the next part for processing while moving the completed part to the next step in the process. By cutting apart the planks into pieces that represent one part, every future operation will run only one part at a time, or in one-piece flow, which facilitates continuous value-added work and reduced takt times. Takt times are the average times between the start of production of one unit and the start of production of the next unit, when these production starts are set to match the rate of customer demand (Ducharme & Ruddick, 2004). It is also important to note that by only being able to make two parts per plank, which is equivalent to using about 33” of 48” of available material, 30% of the material per plank is considered scrap. Future analysis will consider steps to reduce this number significantly.

Figure 10 – Vertical Band Saw

The next couple of steps involve a more automated process for machining all the other features of the product like the peg holes, watch charging slot, and cantilever pocket for miscellaneous items. These features all involve precision milling of either thru-holes or 3D holes, which is only available with a gantry sheet router like the one shown in Figure 11. The sheet router has an extensive travel range of six feet in the X and Y directions and eleven inches in the Z direction, well within the capabilities needed to mill the 5” x 24” blanks. To use this machine, a tool path must be created through a modeling program, which will give the gantry sheet router the directions needed to mill the peg holes, watch charger slot, and 3D pocket on the cantilever piece. Lengths of rubber will be configured in the gridded table of the sheet router to the shape of the 5” x 24” blanks, and then a plank will be loaded onto the rubber frame for each run of programmed tool path. The table has a special feature which will pull air from small channels in the grid, which acts like a vacuum to the blank resting on the surface of the table. The purpose of the rubber frame is to isolate the vacuum seal created by the table to the small plank. This helps fix each plank to the table and prevents the planks from moving during router operation. After operation, the vacuum will be turned off and the routed blank is removed.

Figure 11 – a) Gantry Sheet Router and b) Routed Blank

The instructions that the router will follow to create features, called G-Code, must be made first and is very important, as it provides the sheet router with important information to perform the right milling operations at the right locations. The G-Code for this machine is generated from a 3D model of the wall and cantilever piece in the orientation they will be in during machining. Since the two pieces of the product have not been distinguished on the physical blank, the tool path design must be oriented with respect to a zeroed corner of the plank to know where the paths to be milled are located. This 3D model cannot have the two pieces oriented as they would be after assembly. Instead, they must be oriented on the same datum plane, having the sides of the two pieces which will have the 3D features facing up, perpendicular to the plane, so that all 3D holes can be performed in one tool path operation. Figure 12 shows the converted 3D model produced from element arrangement as a 2D drawing of the two separate pieces laying end to end. The features highlighted in red indicate those that the sheet router will mill and are supplemented with corresponding dimensional data. All cuts will be made with a ¼" circular milling bit except for the inner chamfer of the miscellaneous slot. This feature will be milled with a 45° chamfering bit.

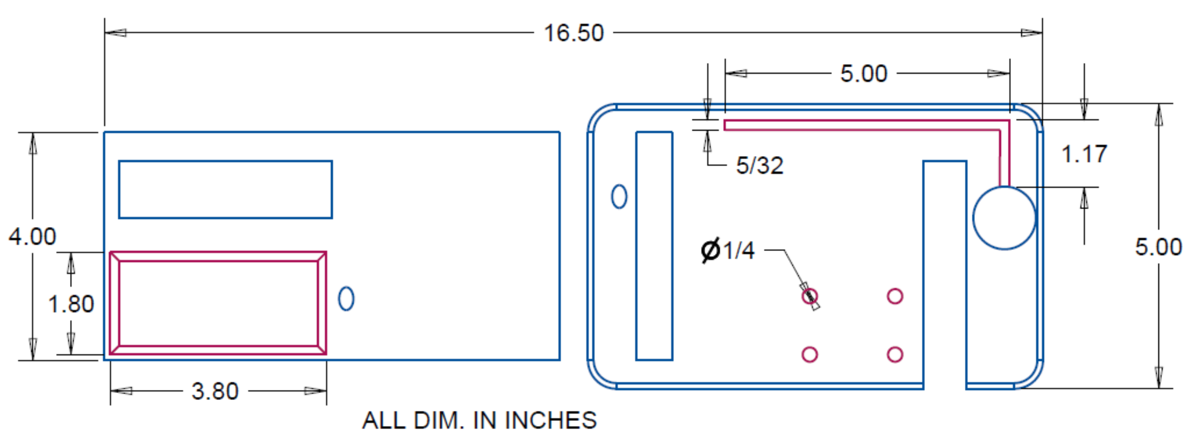

Figure 12 – 2D Creo Drawing of Wall and Cantilever Pieces in Orientation of Sheet Router Blank

Once the milled blank is removed from the sheet router, it will be moved to a cutting machine of similar operation, except this machine uses a small-diameter, high-speed jet of water mixed with abrasive sand to cut through material. This machine called the waterjet cutting machine is useful for making faster cuts with only slightly looser tolerances and has a relatively small cutting length, which is ideal for cutting smaller shapes and features. To use the waterjet cutting machine, the material to be machined must be clamped down to the metal grid suspended over the water table. This restraint is necessary to ensure the material does not get thrown from the cutting table during machining or fall through the grid and sink into the water tank. A zero must be established for each operation of the machine, like the gantry sheet router, and a 2D tool path must be generated from a 3D model to tell the machine where to cut away material. Figure 13 shows an image of the waterjet cutting machine used in this operation and the pieces procured after completing this process. Figure 14 details the 2D drawing used to make the tool path, with cuts to be made highlighted in orange.

Figure 13 – a) Waterjet Cutting Machine and b) Post-Machined Wall and Cantilever Pieces

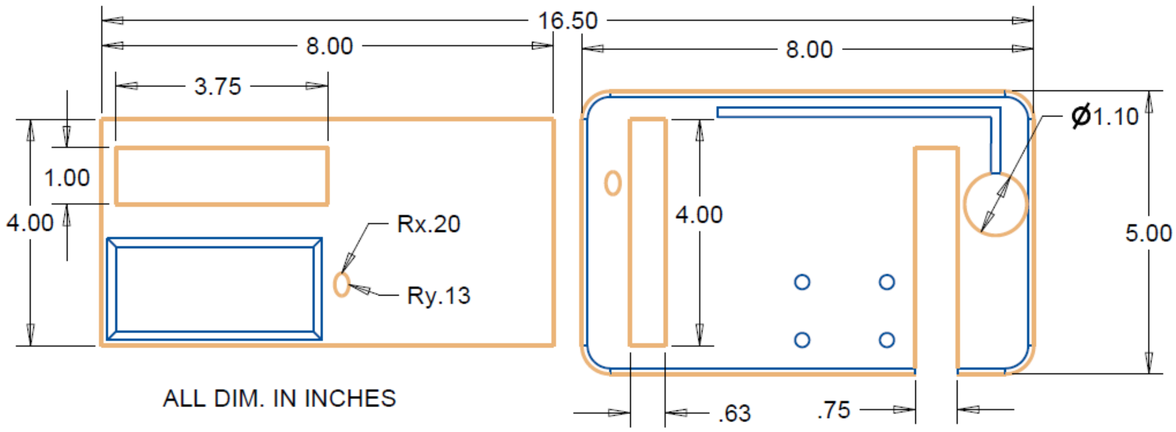

Figure 14 – 2D Creo Drawing for Waterjet Cutting

2.5.3 Alpha Prototype

Since the conception of the Dock of Champions design, priorities remained on compactness, compatibility, and ease of use. Therefore, the initial design was driven by the concept of a simple two-piece assembly that could accommodate most if not all phone charging cables and reliably hold all portable items placed on the docking station including a phone, set of keys, pair of glasses, wallet, two watches, and loose pocket items like change or lip balm. Product volume and lower surface area were reduced significantly to find the minimum space to store all the intended items. Cheap material was used on every facet of the design to determine bare minimum costs of the product and the reasonable margin of profit available for the team. Figure 15 describes the dimensional specifications used for the alpha prototype to achieve these goals while Figure 16 displays an as-built alpha prototype.

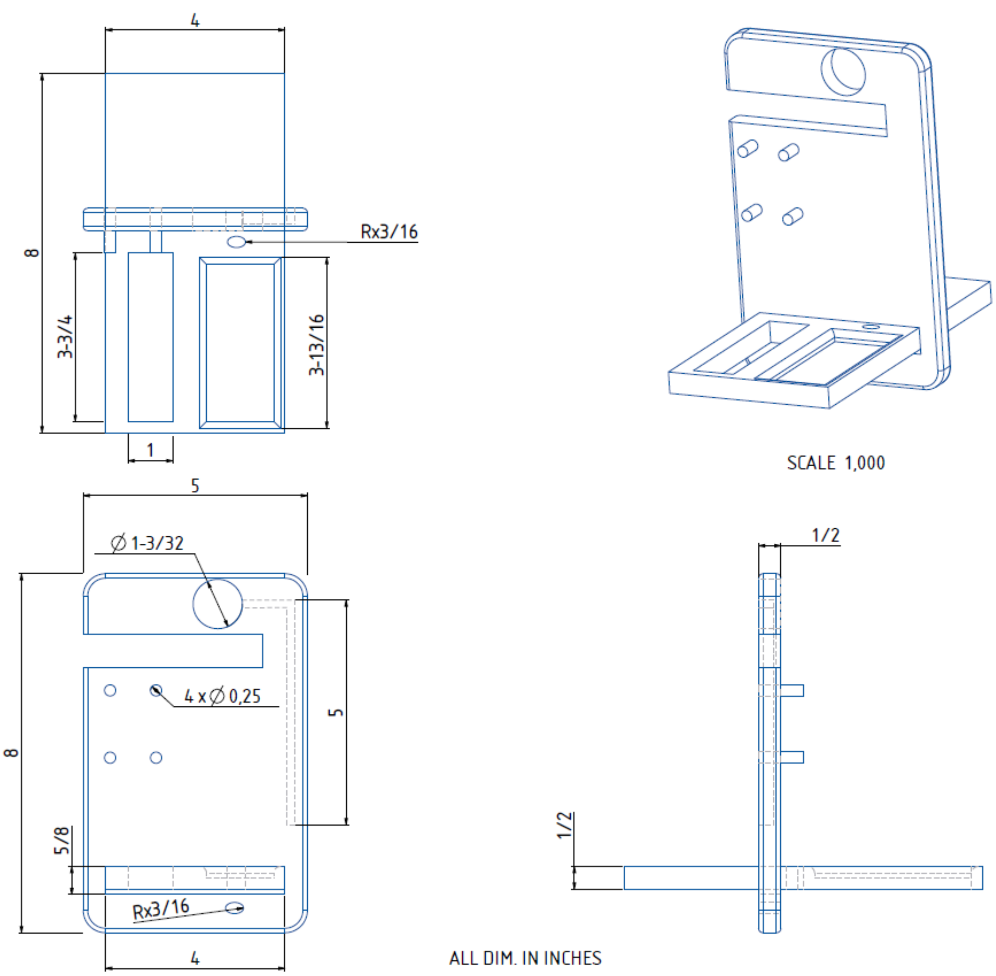

Figure 15 – Alpha Prototype, Two-dimensional Design Drawing

Figure 16 - As-Built Alpha Prototype with and without Portable Items

2.6 Parametric Design (Beta Prototype)

More specific details of the product are confirmed in this stage of the conceptual design. Now that the initial dimensional information, manufacturing processes, and materials required have been established, it is important to understand how these aspects integrate together. This process of clarifying and optimizing the system of features and dimensional values that can significantly alter the product is what is known as parametric design. In this analysis, the design will be investigated with respect to its manufacturability and assembly, commonly known as DFMA, and features that have tight tolerances allowing for little error will also be clarified. As all of the manufacturing and assembly processes have been established up to this point to create an alpha prototype, this analysis will seek to improvement on this design, which will culminate with changes made from customer feedback to synthesize the beta prototype.

2.6.1 Design for Manufacturing and Assembly (DFMA)

DFMA is a crucial step in the conceptual design process that helps companies that mass-produce their products to eliminate waste, including time, and subsequently maximize profit. This design analysis can also improve customer satisfaction by simplifying the process required by customers to assemble the product for use. This analysis is typically broken up into two fields: design for manufacturing (DFM) and design for assembly (DFA). The focus of DFM is to analyze how the configuration and inclusion of design features and the way that they are machined or formed affect the amount of time needed to completely manufacture a single product. Sample methods for optimizing DFM include minimizing the total number of parts, standardizing components and design features, and designing for simplicity and ease of fabrication. DFA refers specifically to how the product is put together after all machining and finishing processes have been performed. Relevant variables include the number and type of fasteners involved, indicators that foolproof the correct assembly method, and minimizing assembly surfaces. Coincidentally, several design decisions for the alpha prototype of the docking station took ease and efficiency of manufacturing and assembly into account and are detailed below. While some of these decisions were briefly detailed in Section 2.5.2, the justifications for these decisions will be detailed here.

Starting with the base pieces of the alpha prototype, DFMA was implemented by minimizing the total number of parts required to manufacture the product. In total, there are three unique "parts" needed to complete this product: the cantilever, wall piece, and four identical hanging pegs. By designing the product with so few and such simplistic pieces, it is easy to understand how it is to be assembled. Simply sliding the cantilever through the slot on the bottom side of the wall piece and inserting the four pegs into the corresponding peg holes on the wall, a user can assemble the docking station in less than a minute. This design choice reduced the amount of material and separate parts that would have had to be bought, inventoried, and monitored. Another significant aspect of its assembly is that it is primarily held together by gravity and implements press-fit technology while still proving to be a structurally robust design. This is a significant factor in that it eliminates the need to buy additional fastening parts or glues that would drive up product costs, lengthen manufacturing and assembly cycle times, and lower potential profits. While functionality is paramount, product performance should not be specified more than what the customer requires, and the docking station proves its simplicity in this way.

The Dock of Champions also incorporates standardized components, in that materials bought for the product were commercially available in-mass and closely fit the specifications for the product dimensions. This has an obvious cost benefit in that commercially standardized parts and materials are cheaper and more reliable. The product also incorporates standardized design features which relates to the types of drilling and milling bits used to cut out these features. As described in Section 2.5.2, the sheet router uses the same tool to mill out the watch charging cable slot as it does the peg holes. This eliminates about 15 seconds of cycle time per product made that the sheet router would have used to change tools had these two features been of different widths.

Material cost and finishing processes were also an obvious means of designing for manufacturing. In Section 2.5.1, initial material selections were made based on the cheapest material found that fit the rough dimensional specifications made for the product and while finishing materials were researched, no clear coat or wood stain was selected in order to reduce the total manufacturing costs. This helped the design team realize the base manufacturing costs per product and, once a customer demand had been established, helped them determine if product margins and lead times would allow for finishing processes like laser-etching and clear-coating.

Waterjet and sheet router drawings used for the alpha prototype were designed for ease of fabrication, another pillar of DFM, by orienting the wall and cantilever pieces along the same plank with all 3D holes facing the same way. This layout is shown in Figure 12. The sheet router which will cut this layout will only have to be run once per product and technicians operating the machinery will not have to waste time reorienting the pieces so that all cuts can be made.

2.6.2 Tolerances

Tolerances are a crucial quality-control tool that determine whether a manufactured part is made to the acceptable limits of the customer. With respect to the actual product, a tolerance is the acceptable variation from any one dimension in the product's design. These tolerances are always set within a range that prevents features and parts from falling apart or not functioning as intended. If certain dimensions of the product are outside of this established acceptable range, then the product is considered defective and unacceptable to sell to a customer. Ideally, every dimension would be machined to tight tolerances, however, this is normally not cost or time efficient. Therefore, it is important to recognize the features and dimensions in every product that have tighter tolerances than others and how to manufacture the product so that all dimensions are kept within those tolerances while minimizing manufacturing costs. Based off initial manufacturing trails completed from the alpha prototype, the Dock of Champions contains only three features that have significant tolerances to discuss.

The first feature that is of concern is the slot in the wall piece in which the cantilever is placed, which is to be only slightly bigger than the ½" thick cantilever. Ideally, the slot thickness should be no less than ½" and no greater than .520", which leaves a .02" unilateral tolerance for the thickness of the slot to still be acceptable. The operation to cut this feature is the waterjet cutting machine, which uses a high-pressure stream of water to cut through the material. The issue that arises with this method of machining is that the cutting diameter of this stream of water is dependent on how close the cutting nozzle of the waterjet is to the blank being machined. The farther away the nozzle is from the part, the wider and less uniform the cuts made will be. Seeing as there are no other ways in which to control the cutting diameter, the most effective plan is to program the toolpath so that the water nozzle will always travel as close to the board in the Z-direction as possible without hitting the board. This ensures that the stream of water cuts the least amount of material outside of what the tool path designates and provides a more accurate part that was designed in the product model. Since the water jet is the most time-efficient cutter for complex thru-hole geometries, all other thru-hole cuts to be made will be done on this operation, except for the peg holes.

The peg holes, being only ¼” in diameter, have a much smaller range for error since the pegs will be pressure fitted into the machined holes. If the hole is oversized by as little as .005”, the pegs that are to be inserted and press-fitted into them will simply fall through. Cutting them any smaller than ¼” will prevent them from fitting in the holes at all. The gantry sheet router is the most effective automated solution for tighter tolerance features. Simply using a ¼” drill bit, the gantry sheet router will plunge four holes described as in Figure 12 that will have minutely small error.

The final tolerance to be set is the width of the watch charging cable slot, which is discovered during testing of the alpha prototype. The tolerance of this slot is driven by how the charging cable rests while being wedged into the slot. If the slot is too big, then the cable will not be constrained well enough in the docking station. However, a smaller slot that more closely fits the size of the charging cable, while a more secure feature, requires an additional tool be loaded and unloaded from the gantry machine during a single operation, which will slightly increase takt times. The diameter of the charging cable was found to be 1/8” wide, so the minimum slot width must be at least that diameter. The next smallest tool diameter used on the gantry router is a ¼” end mill bit, which was found to produce a sustainable but less restrained slot design as those with smaller widths. However, this shortcoming is compromised by avoiding an additional tool change by the gantry router and increasing processing time per part. Initial manufacturing processes designated a 5/32" milling bit to machine the slot for which the watch charging cable will rest. This was changed to a ¼" milling bit that was determined to be an acceptable compromise of the two considered criteria, in that a tool already selected for the operation will be used again to mill the slot and the width of the slot will be narrow enough to prevent the charging cable from falling out of the product.

2.6.3 Customer-Based Design Revisions and Beta Prototype

At this point in the design process, feedback was requested from customers that reviewed the alpha prototypes made and, upon their review, several improvements in the prototypes were made clear. These issues had to be addressed and resolved immediately before finalizing the beta prototype. The first and most identifiable error found was that a typical iPhone® with a standard case installed was too tall for the wall of the docking station, so much so that the smartphone was covering up the watch charging pod, preventing an Apple Watch® from being installed to charge. Pegs for keys and glasses were also found to be too low to the cantilever beam, altogether creating a cluttered station. These errors were fixed by relatively simple measures. First, the wall piece was lengthened by two inches in total. This change only had minor effects on the tool paths of the waterjet cutter and sheet router. The two lower pegs of the four pegs in the alpha prototype design were removed to reduce clutter, as customers relayed that a peg should only be needed for a pair of glasses and a standard set of keys. This correction also slightly improved the cycle time of the product as there were two less holes to machine per product and pegs to install for assembly.

Other issues expressed to the design team included that the wallet slot created on the cantilever board was too small to accommodate some of the wallets used by polled customers. The wallet slot was then widened from 1” x 3.75” up to 1.75” x 4” to accommodate bulkier wallets, which was also an easy correction to make in the waterjet tool path drawing. Another important issue arose where the phone charging port hole did not accommodate every size phone charger and often kept the user from easily pulling out the charger to connect or disconnect the charger from the phone. This issue was resolved by widening the charging cable port hole to accommodate all known micro-USB® and Apple Lightning® cable sizes.

Customers reported that they had trouble keeping the watch charging pod constrained inside the milled slot on the back of the wall piece. This was addressed as a tolerance issue, where the slot had been drilled too wide for the watch charging cord to stay within the wall piece. Changing the slot width would require an additional tool change operation in the sheet router program, which would add about 15 seconds of cycle time per part. To avoid this, a modification in the geometry of the slot was made to better constrain the charging cable. Figure 17 shows this modification to the watch charging cable slot, which now incorporates a bootleg path that better holds the cord to the back of the wall piece and the pod inside the hole of the arm. The slot width was maintained at ¼”.

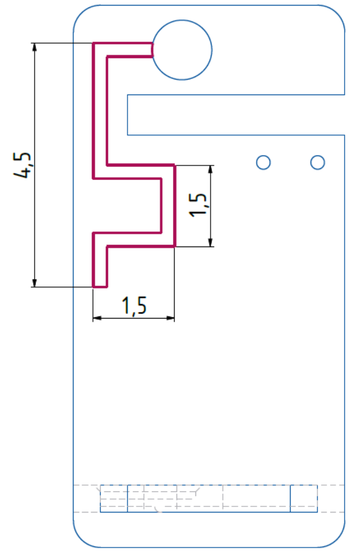

Figure 17 – Modified Watch Charging Cable Slot

Customers also wanted to see more cosmetic appeal and options for customizability for the product. While the concept selected in Section 2.3.4 included some finishing processes, the alpha prototype was devoid of finishing processes to determine maximum profit margin. Since that value was now known (detailed in the financial review of Section 3.2), a cost analysis was performed which included the changes implemented to the beta prototype as well as the addition of a clear coat or a mahogany wood stain. Models were also made of the beta prototypes with these finishing processes performed to generate additional feedback from customers. These models were received with great approval. The difference in alpha and beta prototypes installed with all typical portable items is shown in Figure 18.

Figure 18 – a) Cluttered Alpha Prototype Model b) Modified Beta Prototype Model

Finishing processes were added after the waterjet cutting cycle, as this was the last machining process in the original manufacturing process. At this point, the two pieces of the docking station are cut out from the waterjet machine and separated from the original blank of wood. Sliding the cantilever into the wall piece and installing the pegs proves that the product is near functional, but selected finishing operations must be done before the product is considered finished. The beta prototype only implements one finishing operation which involves applying a wood stain to the two-piece assembly. From preliminary materials selection in Section 2.5.1, red mahogany wood stain was chosen for initial manufacturing trials and alternatives would be considered based on public opinion of the finish. Before applying the stain, the pegs were inserted into the corresponding peg holes. The stain was added to a paint spray gun and an even coat was applied to all surfaces of the part. After two minutes of drying time, the cantilever was inserted in the slot of the wall piece to result in the finished beta prototype.

2.7 Detail Design (Final Prototype)

Very little change was made from beta to final prototype. Only two significant alterations were made here to evaluate profit margin and customer demand. These included laser-etching a logo into the front face of the docking station wall and a material change from sande plywood to whole cherry wood. The plywood material used in alpha and beta prototypes showed a laminated cross-section, which customers found unappealing. Therefore, clear-coated, cherry wood planks were analyzed for cost viability. This material change was implemented not only to the original planks that make the cantilever and wall pieces, but also the dowels which make up the pegs for the product. Cherry wood was found to have a much more appealing product aesthetic, which would likely increase customer demand, but was more expensive per 48" long plank. This decision was justified by the amount of profit that was still gained per unit after the additional material cost had been deducted. This costing analysis is explained in more detail in the financial review of the final prototype in Section 3.2. The manufacturing process does not change with the new material, except that the panel saw is no longer required since the cherry wood is bought pre-cut as ½" x 5" x 48" planks. Therefore, this material change actually shortens the cycle time per part by a small margin.

The final revision made to the final prototype was to laser-etch a logo into the front face of the wall. This was done on a laser-etching machine shown in Figure 18. The product was loaded into the front left corner of the etching table and a 2D drawing of the logo to be etched was loaded to the computer connected to the etcher. For this product, a simple Ole Miss logo is etched to the wall surface as shown in Figure 19.

Figure 19 – Laser Etcher and Post-Process Wall Piece

A quality issue was brought forward by the CME faculty after beta prototype submission and involved the waterjet cutting machine. Initially, there were only two vices that clamped the post-routed plank to the cutting deck of the waterjet. This prevented splash back from the water below the deck from moving the plank during cutting. However, once one of the two pieces of the unit were cut from the plank, the splash back was able to move the parts around. This created a safety and quality issue. A possible hazard was that the displaced pieces of the unit could bounce up over the plank and run into the cutting nozzle. This would break the nozzle on the waterjet cutting machine and put the waterjet machine out of commission for as long as it took to replace the nozzle. If either of the pieces were displaced while the program was running, then there was the possibility of the waterjet incorrectly cutting the pieces as modeled in the tool path. To correct this issue, a bridge element was added between the two pieces of the tool path which kept the two pieces together and constrained to the clamped plank until the waterjet cutting process was completed. The corrected tool path of the waterjet cutter with the added bridge element is shown in Figure 20. Once the unit was cut and removed from the waterjet, the bridge was broken by hand and the ends of the two pieces were sanded smooth with a rotary sander.

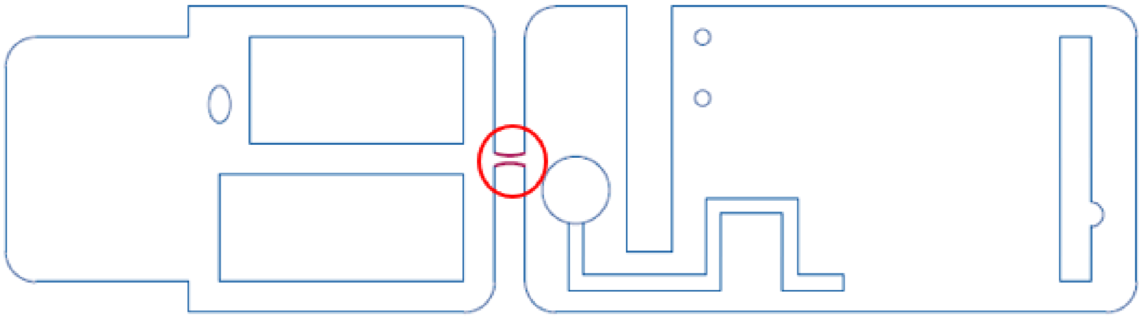

Figure 20 – Updated Waterjet Tool Path with Added Bridge Element

2.7.1 Compile Engineering Drawings

An essential component required before releasing a new product to the market is to compile and submit a complete engineering drawing of the product with all primary dimensions and specifications. This gives customers, design teams, and any who wish to review the product specifications a reference which includes all the dimensional, geometrical, and architectural decisions of the design. As these components can change up until the final prototype, the finalized drawings should not be submitted until this point in the design process. In the same token, the engineering drawing should not change at all after being submitted. Any design changes implemented after this point will not be consistent with the design drawing published or will require time to republish a corrected design drawing, which is usually not good engineering practice. Figure 21 shows the finalized engineering drawing for the Dock of Champions docking station with all primary dimensions, and Figure 22 is a snapshot of a completed, as-built final prototype of the Dock of Champions.

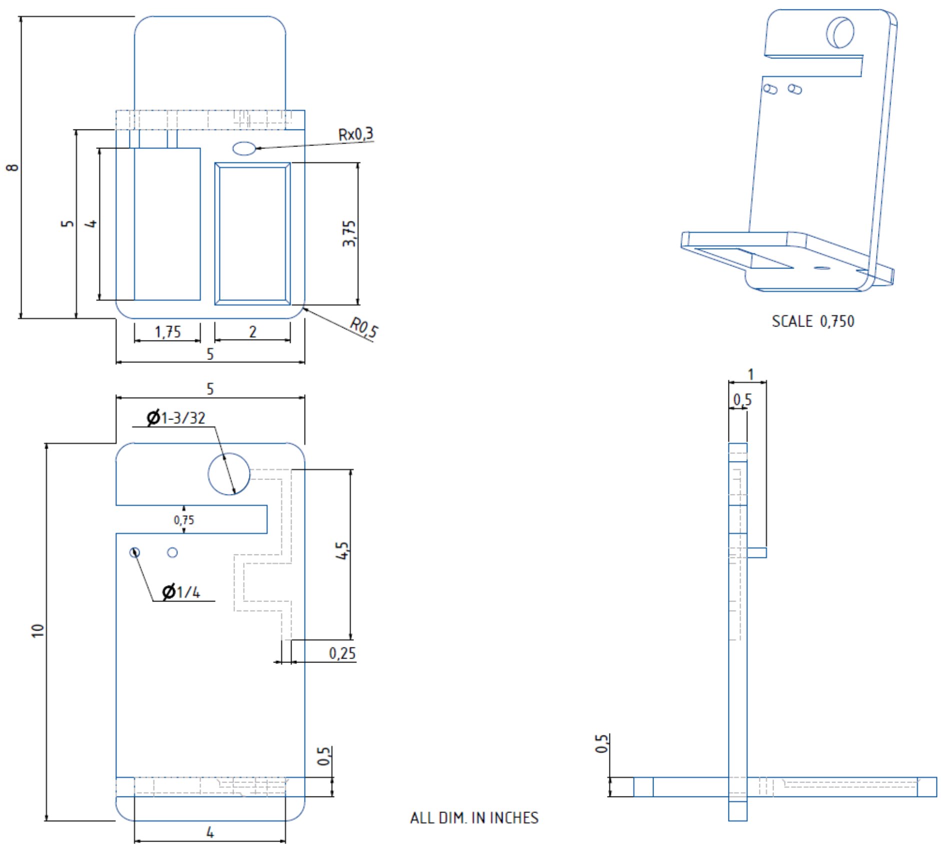

Figure 21 – Finalized Engineering Drawing of Final Prototype

Figure 22 - As-Built Final Prototype

3 Marketing and Financial Review

3.1 Marketing Considerations

The key to successful marketing is to first understand the target market for which the product is intended. Once this important factor is established, the easier it will be to develop a marketing strategy that draws interest to the product. The target market of the Dock of Champions includes University of Mississippi Special Events and professionals both young and old that value a structured and organized work life. The docking station is to be emphasized as a product that will increase convenience, while also being an appreciable keepsake for alumni and visitors of the university. Another key aspect of the product's marketability is its ability to fulfill customer needs. As detailed in Section 2.2, compactness and compatibility with all typical portable items are two of the most crucial essential characteristics that make this product valuable, so those will be emphasized in all advertising operations.

Product differentiation is also key to influencing customers to buy the marketed product over other competitive products. The docking station will differentiate itself from others based on a few aspects of its fabrication. The first aspect is its location of production, made locally, right in the middle of campus at the Center for Manufacturing Excellence. Potential customers will appreciate this simple fact that the product was made locally, which adds a sentimental value that other outsourced products will not have. The Dock of Champions will also have multiple customizable features, giving the customer their choice of different wood finishes and an array of Ole Miss themed logos and designs. The docking station also features easy assembly, only requiring the cantilever to be slide through the corresponding slot in the wall piece. Since the product is also easily disassembled, the product can also be marketed as a portable product, being easily transported from home to work or wherever a customer may spend their workday.

There are multiple means of marketing the Dock of Champions to the target market, especially to the younger spectrum of potential customers. Social media promotion is a cheap and very effective way to expose the product to younger customers. Popular social media sites to market the product through could include Instagram, Facebook, Twitter, and Snapchat, among others. These promotional ads can also be made specific to many annual holidays or seasons. For example, the Dock of Champions could be pitched as a great Christmas or birthday gift for friends or family, while also being marketed as a wonderful "back-to-school" tool for the successful student. Aside from online sales, this product could be sold through local retail stores in and around the university area, including cell phone stores, local crafting shops, and bookstores. Since the base model of the docking station accommodates Apple® smartphones and smartwatches as well as Android® smartphones that use a microUSB® port, it may also be beneficial to seek an Apple® and Android® endorsement for the Dock of Champions as a consumer item that these companies would recommend for their products. This would be a huge plus in the eyes of consumers, as they would know that the docking station was designed to the standards of their products.

3.2 Financial Review

Costing analysis for a conceptualized and manufactured product is essential to determine the financial viability of bringing the product to market. It is of the utmost importance to know whether the design team or company that will be mass-producing the product will be gaining a profit per unit sold or will have be losing money with every product that is made. This directly affects the overall success of the product and thus, a financial review is necessary to completely understand where every cent that relates to the production cost of the product comes from. The financial review of this product will be differentiated by the alpha, beta, and final prototypes presented in design. The financial review will determine the total product cost by factoring all direct material and labor costs, as well as the total factory overhead and operating costs. This total product cost will then be used to choose a starting sales price.

Some general assumptions were made for all financial reviews completed. The simulated product realization simulation does not include any definite fixed costs; however, this number is almost always present in a real-world scenario and determines the payback period for the product, which is the number of units required to be sold before the product pays off its fixed cost expenses and starts to generate a profit for the company. The only real fixed costs that can be defined in this simulation include R&D expenses in the form of material, labor, and overhead costs, which adds up to about $3,000 in fixed costs. This value was found by first summing the total prototyping material costs accrued (around $700) with the labor costs of the design team. The labor costs was found by multiplying all hours logged by the design team (80 hours) by $10 per hour ($800 total). This sum comes to $1500. Overhead costs from machine time during prototyping must also be implemented. Since the total operation time for the machines was not timed during the prototyping phase, an estimated factor of 2 will be multiplied to the original sum of materials and labor to account for overhead. This brings the total fixed costs to $3,000, which will be deducted from the total contribution margin to determine the total profit generated by the company at any time. All labor costs would be determined based on a $10 per hour wage and the operating costs per hour of all machines used in the CME factory floor were determined by the faculty that manage the facility.

Simulated mass-production of every prototype created is ideal to more accurately determine the expected labor and overhead costs associated with each prototype. However, the alpha and beta prototypes did not undergo these trials, so estimates were made for time needed on each process for each prototype and a 20% wasted time factor was applied to simulate a 'worse-case' scenario that generates the most variable costs.

3.2.1 Alpha Prototype Budgeted Costing Analysis

The priority for this prototype was to maximize the profit margin in as many avenues as possible, including material and manufacturing options. As decided from initial material and manufacturing process selection, the cheapest material and the least amount of processes were selected to achieve that goal. Finishing processes were not considered in this analysis, as these are usually unnecessary operations and are avoided to maximize profit margins.

Direct material costs consist of all materials purchased that become a part of and are value-adding to the overall product. The alpha prototype used a sande plywood that was supplied at $31.95 per board and basswood dowels that were $0.86 per 48" length. The direct material costings associated with these materials are shown in Table 9.

Table 9 – Alpha Prototype Direct Materials Costing

Direct Materials Costing		
Material	Details	
Whole Unit Plank (5" X 16")	1/2" X 4' X 8' Sande Plywood	$31.95 total cost per sheet
	# of planks cut per board	36
	Cost per board	$31.95
	Cost per unit	$0.89
Pegs (1”)	48" Basswood Dowel	$0.86 total cost per dowel
	# of pegs per dowel	44
	Cost per dowel	$0.86
	Pegs per unit	4
	Cost per unit	$0.08
	Total Material Costs	$0.97

Direct labor costs consist primarily of the wages paid to workers for operating machinery, moving products along the overall production process, and any other manual labor directly involved with creating the products. All labor costs for the alpha prototype are developed for each process from Table 10.

<u>Table 10 – Alpha Prototype Direct Labor Costing</u>

Direct Labor Costing	Details	Value
Basic factory floor labor	Sawing wood, placing wood into CNC sheet router, milling, and transporting to and from different stations	
	Time @ Panel Cutter	
	Number of cuts	14
	Time per cut	60
	Total seconds	840
	Total units cut	36.0000
	Seconds per unit	23.3
	Hour conversion	0.0065
	Wasted Time Incorporation	20%
	Actual time	0.0078
	Wasted movement (wrt to time)	5.00%
	Total time after wastes	0.0082
	Wage per hour	$10.00
	Total cost per unit	$0.08
	Time @ Vertical Band Saw	
	Units per plank	2
	Seconds per plank	5.0000
	Seconds per unit	2.5
	Hour conversion	0.0007
	Wasted Time Incorporation	20%
	Actual time	0.0008
	Wasted movement (wrt to time)	5.00%
	Total time after wastes	0.0009
	Wage per hour	$10.00
	Total cost per unit	$0.01
	Time @ Sheet Router	
	Minutes per unit	2.5
	Hour Conversion	0.0417
	Wasted Time Incorporation	20%
	Actual time	0.0500
	Wasted movement (wrt to time)	5.00%
	Total time after wastes	0.0525
	Wage per hour	$10.00
	Total cost per unit	$0.53

Direct Labor Costing	Details	Value
	Time @ Water Jet	
	Minutes per unit	3
	Hour Conversion	0.0500
	Wasted Time Incorporation	20%
	Actual time	0.0600
	Wasted movement (wrt to time)	5.00%
	Total time after wastes	0.0630
	Wage per hour	$10.00
	Total cost per unit	$0.63
	Assembly Time (Dowels)	
	Parts to assemble per unit	4
	Seconds per part assembled	10
	Total Seconds	40
	Hour Conversion	0.01111
	Wasted Time Incorporation	20%
	Actual Time	0.0133
	Wasted movement (wrt to time)	5.00%
	Total time after wastes	0.0140
	Wage per hour	$10.00
	Total cost per unit	$0.14
	Total labor cost per unit	$1.39

Total overhead costs mainly consist of the operating costs associated with each machine involved in the process. Their operating cost per hour was given by the CME faculty and were multiplied by the cycle time of each part made. These operating costs could be related to electrical power costs to run the machine and/or indirect material used by the machine to add value to the product. Most manual tools were given an operating cost between $10 and $40 per hour while more sophisticated and automated systems were operated at $100 per hour. The total overhead costs for the alpha prototype are developed in Table 11 based on these operating costs.

Table 11 – Alpha Prototype Total Overhead Costing

Factory Overhead Costing	Details	
Depreciation & rent	Based on cycle time recorded from production trials	
other Indirect material costs		
	Time @ Panel Cutter	
	Minutes per unit	5.38
	Hour conversion	0.0897
	Operating cost per hour	$10.00
	Total cost per unit	$0.90
	Time @ Vertical Band Saw	
	Minutes per unit	5.38
	Hour Conversion	0.0897
	Operating cost per hour	$10.00
	Total Cost per unit	$0.90
	Time @ Sheet Router	
	Minutes per unit	5.38
	Hour Conversion	0.0897
	Operating cost per hour	$100.00
	Total Cost per unit	$8.97
	Time @ Water Jet	
	Minutes per unit	5.38
	Hour Conversion	0.0897
	Operating cost per hour	$100.00
	Total Cost per unit	$8.97
	Total Overhead Costs	$19.73

Now that all variable costs have been determined, a total product cost can be calculated as shown in Table 12. To find the total profit margin, a sales price must be chosen. This value is directly up to the design team, but initial research should give a good indicator for the acceptable price range that customers would be willing to pay for the product. For the alpha prototype, the sales price was established as $24.99, which is considerably lower compared to similar products priced at $60 up to $100. According to the table, the contribution margin is shown to be $2.91, just over 11% of the sales price, which is a reasonable amount of margin to incorporate more quality materials and processing. It is important to note that the cycle times for each operation here are just estimates and later analysis with real production trial data will provide more accurate labor costs. The break-even point (BEP) units was determined by dividing the total fixed costs by the contribution margin calculated. This gives the total amount of units needed to be produced and sold before the profit generated by the product pays back the initial fixed costs.

Table 12 – Alpha Prototype Total Unit Cost and Profit Analysis

PER UNIT COSTS	
Total Direct Material Costs	$0.97
Total Direct Labor Costs	$1.39
Total Factory Overhead Costs	$19.73
TOTAL PRODUCT COST	**$22.08**
Sales Price	$24.99
Variable Costs	$22.08
Contribution Margin	**$2.91**
Contribution Margin %	11.65%

BEP Units	1030
BEP Dollars	$25,743.12
Less variable costs	$22,743.12
Contribution margin	$3,000.00
Less fixed costs	$3,000.00
Gross profit	$0.00
Fixed Costs	$3,000.00
Target Profit	$2,500.00
Required Units	1888.58
Required Sales	$47,195.71

3.2.2 Beta Prototype Budgeted Costing Analysis

The improvements made to the product since alpha prototype culminated into a final beta prototype that is detailed in Section 2.6. The financial impact is worth knowing, as some processes were lengthened, shortened, and created to better meet customer needs or shorten lead times. One of the significant changes was the sheet router machining time, which directly affects the overhead and labor costs of the product. By removing two pegs holes from the sheet router tooling program, standardizing the watch charging cable slot to the same size of the peg holes (effectively removing a tool change sub-procedure), and adding a longer end mill slot for the watch charging cable slot, the tool program time was remeasured and found to be 132 seconds long, slightly shorter than the 150 second run time of the sheet router. Another significant change includes the addition of a wood stain, which would inevitably lengthen the cycle time, increase labor costs, and reduce overall profit margin. However, this finishing process generates more customer base due to more favorable aesthetic appeal.

Table 13 shows the calculated product costs specific to the modified sheet router process and the added wood stain operation. The overall unit costs are then shown with the modified labor and overhead costs with a revised profit analysis. For brevity, only the changes in the costing analysis from alpha to beta prototypes are presented here. While the labor costs were increased due to added finishing process, the shortening of the sheet router cycle subtracted most of the difference to the variable costs of the product. This is due to the expensive operating costs of the sheet router which makes every second saved on this machine much more valuable than on manual machines. An important clarification to make is that while these changes implemented in the beta prototype only slightly reduced the profit margin, they did not necessarily improve cycle times. Production cycle time research presented in Section 4 will evaluate in greater detail how the updated cycle time compares to a given customer pace. The revised overall unit costs and profit analysis shown in Table 14 shows that the BEP increased slightly and a $2,500 target profit would require about 14 days of production, assuming 8-hour days of production at 10 units per hour (80 units per day). This is an acceptable profit gain per unit, however somewhat unrealistic due to implementing the ‘best-case’ scenario assumptions.

Table 13 – Beta Prototype Product Costing Modifications

Sheet Router Labor Costing	
Minutes per unit	2.2
Hour Conversion	0.0367
Wasted Time Incorporation	20%
Actual time	0.0440
Wasted movement (wrt to time)	5.00%
Total time after wastes	0.0462
Wage per hour	$10.00
Total cost per unit	$0.46

Wood Stain App. Labor Costing	
Time to apply stain (seconds)	93
Hour Conversion	0.025833
Wage per hour	$10.00
Total cost per unit	$0.26

Table 14 – Beta Prototype Overall Unit Costs and Profit Analysis

PER UNIT COSTS	
Total Direct Material Costs	$0.97
Total Direct Labor Costs	$1.51
Total Factory Overhead Costs	$19.73
TOTAL PRODUCT COST	**$22.20**
Sales Price	$24.99
Variable Costs	$22.20
Contribution Margin	**$2.79**
Contribution Margin %	11.15%

Fixed Costs	$3,000.00
BEP Units	1,076.46
BEP Dollars	$26,900.84
Less variable costs	$23,900.84
Contribution margin	$3,000.00
Gross Profit	$0.00
Target Profit	$2,500.00
Required Units	1,973.52
Required Sales Dollars	$49,318.21

3.2.3 Final Prototype Budgeted Costing Analysis

The important changes between beta and this final prototype included the inclusion of an additional finishing process and substituting cheaper plywood with higher quality and more expensive whole cherry wood. Feedback from customer base also made clear that customers would be willing to pay more for a product made of more quality material, so the sales price was increased from $24.99 to $44.99. Production trials were completed at this point, so accurate automated run times and manual time involved with setting up and removing parts from machines was able to be incorporated in this costing analysis. The direct materials costing has the most significant impact to the bottom line and is shown in Table 15.

Table 15 – Final Prototype Direct Materials Costing

Material	**Details**	
Cherry Whole Wood	1/2" X 5" X 48"	$29.99 Per plank
	Length of plank in inches	48
	Length cut per unit in inches	19
	Total units per plank	2.53
	Actual amount	2
	Cost per unit	$15.00
Cherry Round Dowel	¼" x 48"	$8.02
	Inches per dowel on product	1
	Pegs cut per dowel	44
	Total cost of dowel	$8.02
	Cost per individual cut dowel	$0.18
	Number of cut dowels per product	2
	Cost per unit	$0.36
	Total material cost per unit	$15.36

Labor and Overhead costs also changed based on the most up-to-date data for machine run times and manual labor times. The final prototype costing for labor and overhead are shown in Table 16 and 17, respectively. Note that on top of a laser etching process, a sanding operation was added due to a quality and safety issue addressed in Section 2.7.

Table 16 – Final Prototype Direct Labor Costing

Basic factory floor labor			
Time @ Vertical Bandsaw		**Dowel Assembly Time**	
Time cutting Planks	10	Parts to assemble per unit	2
Time cutting Dowels	6	Seconds per assembly	5
Total time cutting (seconds)	16	Total Seconds	10
Hour conversion	0.00444	Hour Conversion	0.00278
Wage per hour	$10.00	Wage per hour	$10.00
Total cost per unit	$0.04	Total cost per unit	$0.03
Time @ Sheet Router		**Time @ Laser Etcher**	
Setup time	5	Total seconds at etcher	118
Program running time	132	Hour conversion	0.03277
Removal time	6	Wage per hour	$10.00
Total time at machine (seconds)	143	Total cost per unit	$0.33
Hour conversion	0.03972		
Wage per hour	$10.00	**Clear Coat Time**	
Total cost per unit	$0.40	Time to apply clear coat (seconds)	93
		Hour Conversion	0.02583
Time @ Water Jet		Wage per hour	$10.00
Setup time	35	Total cost per unit	$0.26
Program running time	113		
Removal time	19	**Sanding time**	
Total time at machine (seconds)	167	Time at sander (seconds)	62
Hour conversion	0.04638	Hour Conversion	0.0172
Wage per hour	$10.00	Wage per hour	$10.00
Total cost per unit	$0.46	Total cost per unit	$0.17
		Total Direct Labor Cost	$1.69

Table 17 – Final Prototype Overhead Costing

Based on cycle times recorded from production runs	
Time @ Vertical Bandsaw	
Minutes per unit	5.38
Hour conversion	0.089666667
Operating cost per hour	$10.00
Total cost per unit	$0.90
Time @ Sheet Router	
Minutes per unit	5.38
Hour conversion	0.089666667
Operating cost per hour	$100.00
Total cost per unit	$8.97
Time @ Water Jet	
Minutes per unit	5.38
Hour conversion	0.089666667
Operating cost per hour	$100.00
Total cost per unit	$8.97
Time @ Laser Etcher	
Minutes per unit	5.38
Hour conversion	0.089666667
Operating cost per hour	$40.00
Total cost per unit	$3.59
Total Overhead Costs per Unit	$22.42

The overall unit cost for the final prototype is shown in Table 18. Clearly, the significantly increased material cost and the two added processes' labor and operating costs made a large dent into the contribution margin. However, the increased sales price compensated for the increased costs. Where initially over 1000 units needed to be sold, now just over 500 units need to be sold to pay back fixed costs. If a $2,500 profit were the target, the data shows that about 1000 units need to be sold.

Table 18 – Final Prototype Total Unit Cost and Profit Analysis

PER UNIT COSTS		***PROFIT ANALYSIS***	
Total Direct Material Costs	$15.36	Fixed Costs	$3,000.00
Total Direct Labor Costs	$1.69	BEP Units	543
Total Factory Overhead Costs	$22.42	BEP Sales	$24,441.69
TOTAL PRODUCT COST	**$39.47**	Less variable costs	$21,441.69
Sales Price	$44.99	Contribution margin	$3,000.00
Less Variable Costs	$39.47	Less fixed costs	$1,000.00
Contribution Margin	**$5.52**	Gross profit	$2,000.00
Contribution Margin %	12.27%		
		Fixed Costs	$3,000.00
		Target Profit	$2,500.00
		Target Profit Units	996
		Target Profit Dollars	$44,809.77

Figure 23 shows a visual representation of the profit analysis as more products are built. The chart shows that the total profit will increase linearly with an increase in units sold and a $7,000 profit is reached once about 4000 units are sold.

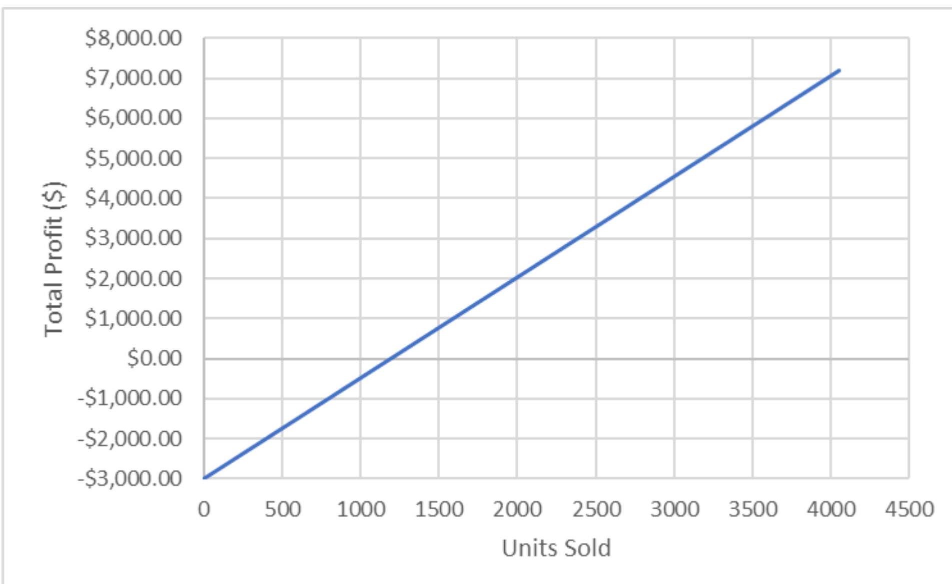

Figure 23 – Profit Trend of Final Prototype vs. Units Sold

4 Manufacturability and Production

The most important aspect of design realization after the product has been created and finalized is to optimize the process design that manufactures the product. This is very crucial to address before beginning production ramp-up because the production method and the subsequent amount of time, space, and material needed can have a significant impact on the product's cost per unit and lead times. Lead times are especially important, as they must always be smaller than the takt time for the product as determined by the customer demand for the product. For this analysis, there is no true customer base that can be evaluated for demand, therefore the CME faculty establish an arbitrary quota that is the assumed product takt time. For the docking station, the assumed takt time is 10 units per hour which is equal to a unit produced every six minutes. Production trials will be conducted on the CME factory floor with the initial layout used to fabricate the product to determine an initial cycle time. Once all process improvements have been made, production trials will be conducted again to generate a new cycle time that will be compared to the initial cycle time and required takt time.

4.1 Initial Considerations for Production

The 'initial process layout and design' is considered the layout and process submitted with the final prototype design. The layout will be analyzed to determine the amount of wasted steps and time used to transport the product between processes. This is an easier component of the production process to improve as the solution is merely a matter of moving machines to a closer proximity to one another. Some machines, like the waterjet cutter and sheet router, cannot be moved however, so other portable machines must be moved to the non-portable machines, as appropriate, and in the correct order.

The process design considers the more fundamental and specific actions taken throughout the process that have the potential for improvement. This includes automated tool paths, loading and unloading parts, the tools and styles used to complete processes, and more. Video recording will be taken during initial and final production trials to better observe those actions that can be improved or possible removed.

4.1.1 Initial Process Layout

Figure 24 shows an eagle-eye view of the initial production layout in the CME factory floor for the docking station process. The visual shows the path that the product travels from the first step to the last and all the machines that are visited to completely manufacture it. Blocks labeled “C” indicate the control panel to start the computer numerical control (CNC) operated machines. Obvious signs of improvement exist that create wasted space, time, and steps. For example, the product makes a long loop around the machine shop before being completed and is even forced to travel around machinery that is irrelevant to its fabrication. The total time to complete this path was found to be an average of about 45 seconds. Using this process design in full-scale production would likely result in falling behind lead times simply due to the amount of time needed to traverse the whole process layout path. This process will need to be modified so that the portable machines are moved closer to those that are fixed and away from machinery that is not used to manufacture the product.

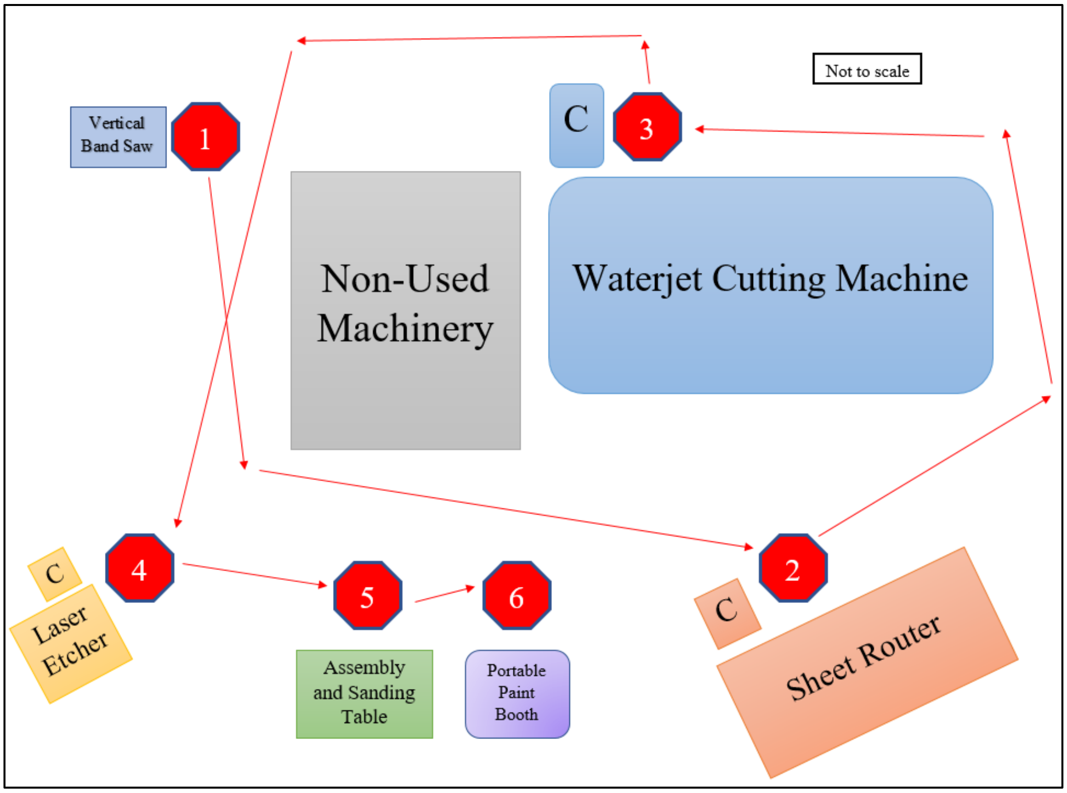

Figure 24 – Initial Process Layout & Flow for Docking Station Production

4.1.2 Initial Production Trails

Production trials were conducted by starting with a stock plank of wood and wood dowel and timing each element of the process. The timing of each process was broken down by setup and removal time (if applicable) and value-added work time. Four trials were conducted to generate reliable data and two hypothetical trials were generated for the average and minimum time of each step. Table 19 shows the trial data recorded for the entire initial process cycle. From this information, the average total time to create a part is found to be 12 minutes and 11 seconds. Although this is higher than the established takt time, this is not reflective of the amount of time between each part completed during production. The true cycle time is equal to the amount of manual labor time per unit, since the automated work will be completed simultaneously to the manual labor and takes less time to complete than manual labor. The total manual labor per unit was found to be 7 minutes and 32 seconds, which is 92 seconds above the established takt time. This requires more than one person to be completing manual work for this process to prevent falling behind the customer pace. Hiring an additional worker would double labor costs which would make a significant impact to profits, so process improvements must be made to mitigate this from occurring.

Table 19 – Initial Production Trail Data

	Time (s)					
Process	Trail 1	Trial 2	Trail 3	Trial 4	Average	Minimum
1) Vert Band Saw	17	17	16	16	17	16
Planks	11	11	10	10	10	10
Dowels	6	6	6	6	6	6
2) Sheet Router	160	157	144	147	152	144
Setup	17	17	6	5	11	5
Program Run	132	132	132	132	132	132
Removal	11	8	6	10	9	6
3) Waterjet	198	212	167	178	189	167
Setup	54	69	35	39	49	35
Program Run	113	113	113	113	113	113
Removal	31	30	19	26	27	19
4) Laser Etcher	118	118	118	118	118	118
5) Sander	62	68	96	121	87	62
6) Assembly	20	20	20	20	20	20
6) Clear Coat	117	109	93	100	105	93
Total Transport Time	46	42	48	43	45	42
Total	738	743	702	743	732	662
(in minutes)	12.30	12.38	11.70	12.38	12.19	11.70
Manual Time (s)	488	493	452	493	482	411
(min)	8.13	8.22	7.53	8.22	8.03	7.53
Machine Time (s)	250	250	250	250	250	250
(min)	4.17	4.17	4.17	4.17	4.17	4.17

Demand (parts per hour)	10	People required	1.256
Takt time (minutes per part)	6	Excess Time (seconds)	92
Cycle Time (minutes)	7.53		

4.2 Improvements Made

Many points of improvement could be made to both the process layout and the overall manufacturing process in order to reach cycle time. The goal is to optimize the cycle time so that it matches that of the takt time. This is because there are additional costs associated with the cycle time being both above and below this time period. Having the cycle time above the takt time has more obvious consequences, as it means that production is not meeting the quota of the customer demand. This must be resolved by either cutting out manual time or adding additional workers that allow for double the work to be done in the same amount of time. This is not recommended as it will also increase direct labor costs by a factor of how many workers that are now working the production line. Having the cycle time too far below the takt time is a less obvious expense. When this occurs, one of two things happen: either the workers are producing more product than is demanded or there is idle time between each part. In the first scenario, a company would be accruing additional costs to inventory the unsold parts. In the second scenario, the company would be wasting money on labor and machine time during the idle periods. Therefore, it is important that the cycle time be optimized to the takt time so that the period of production matches that of customer demand. Alterations in the process layout and design will consider this optimization.

All process improvement decisions will also be based on a key concept to be implemented called one-piece flow. This process prevents what is known in the manufacturing world as batching. Batching occurs when more than one part is processed at a particular station in a manufacturing process. When this happens, parts are unnecessarily waiting at the end of the station's process for the other parts in the "batch" to be completed. This increases the average cycle time of each unit being produced and has been proven to lower the amount of parts produced in a day. The more optimal process concept, one-piece flow, designs the process so that one unit is processed at each station at a time from the start of the process to the end.

4.2.1 Improved Process Layout

The process layout was found to be unnecessarily spread out, which allowed for wasted time in the process to transport the parts from one station to the next. To mitigate this waste, all portable machines were moved closer to those that were not considered moveable, such as the sheet router and waterjet cutting machine. The vertical band saw, laser etcher, sanding & assembly table, and the portable paint booth were all able to be moved, so these were relocated in order of operation around the waterjet and sheet router. The process layout was also reconfigured into a U-shape, which reduced the travel time between the last and first station of the product cycle for the worker. Another key change was reconfiguring the water jet to be operated from the opposite side of the table, which only involved moving the portable control panel and reconfiguring the water line. Figure 25 details the corrected process layout and product flow diagram for the Dock of Champions. Time trials for the total transport time between these stations was found to be an average of 18 seconds, which is a 27 second improvement from the initial production layout scheme.

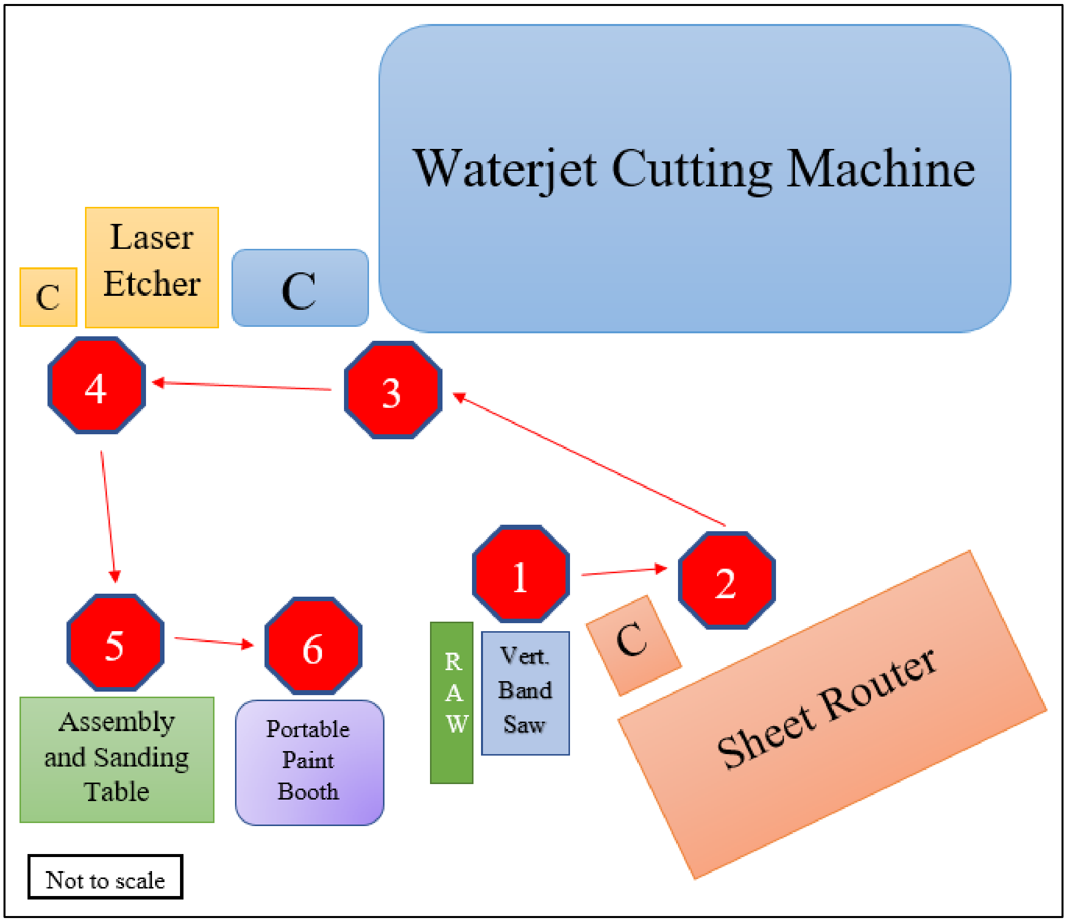

Figure 25 – Improved Process Layout & Flow for Docking Station Production

4.2.2 Improved Production Trials

The initial production trials show that the cycle time is 92 seconds above the takt time, which means that improvements need to be made to the manufacturing process to cut down on manual labor. The first big change that was implemented was an increase in the cutting speed of the waterjet. While this may initially seem like an automated process, which is unrelated to the cycle time of the product, the operation of this machine is actually required to be supervised by a worker for safety concerns. The waterjet cutting machine always carries the risk of displacing cut material that would severely damage the waterjet nozzle if the cutting path were to cause the nozzle to run into this displaced material. For this reason, the entire waterjet process is considered manual work. By reducing the program run time of the waterjet, the worker can continue with other processes to meet the takt time. This was done by doing process tests on the waterjet tool path with the cutting speed increased by 50%. Parts were inspected with those run at the original cutting speed and minute differences were observed. Therefore, the increased cutting speed was implemented as the standard of the manufacturing process.

Another important improvement made was removing an unnecessary tool change from the sheet router program. This involved moving the operation that cuts a reference slot for the waterjet right behind the operation that mills the ¼" slot for the watch charging cable. Initially, these operations in the tooling program were separated which meant that the gantry had to waste time swapping back to a tool that it had previously used. Correcting this order of operations reduced the program time by 21 seconds. While this does not directly apply to the cycle time, it is still important to ensure the automated machine time does not exceed that of the manual time, or the automated time would then be the driving variable to compare to takt time. This would indicate wasted labor since workers would be waiting for the machine to finish each part produced. Due to this correction, the total sheet router program time is now 111 seconds.

The sanding and clear coat operations were other big areas of improvement. Sanding was taking longer than expected to sand the bridge from the wall and cantilever pieces. This was because the sand paper used with the rotary sander was found to be too fine. Resolving the wasted time required only for heavier grit sandpaper to be used when sanding the bridge from the parts. Time trials conducted after this implementation showed a 30 second decrease in time to sand the bridge away. Initially, the clear coat glaze was applied via a spray gun, however it was found that applying the glaze from a paint can with a regular paint brush was found to not only slightly reduce the cycle time for the product, but also ensure a more uniform coat of glaze for each part. Time trials for this alternate process showed the clear coat application was reduced by about 15 seconds on average.

The improved production trials that were conducted implemented all previously mentioned improvements. Table 20 shows the data from the improved production trials with revised cycle time values and required workers. The new cycle time was found to be 5 minutes and 23 seconds, which is 37 seconds below takt time. While this is better than the initial cycle time, the improved production cycle is now producing units slightly faster than the customer pace. To compensate for this small amount of idle time, a revamped marketing strategy could be implemented that could draw in more customers and lower the takt time to match the improved cycle time.

Table 20 – Improved Production Trail Data

	Time (s)					
Process	Trail 1	Trial 2	Trail 3	Trial 4	Average	Minimum
1) Vert Band Saw	17	17	16	16	17	16
Planks	11	11	10	10	10	10
Dowels	6	6	6	6	6	6
2) Sheet Router	139	136	123	126	131	123
Setup	17	17	6	5	11	5
Program Run	111	111	111	111	111	111
Removal	11	8	6	10	9	6
3) Waterjet	148	162	117	128	139	117
Setup	54	69	35	39	49	35
Program Run	63	63	63	63	63	63
Removal	31	30	19	26	27	19
4) Laser Etcher	118	118	118	118	118	118
5) Sander	50	65	60	54	57	50
6) Assembly	20	20	20	20	20	20
6) Clear Coat	102	94	78	85	90	78
Total Transport Time	18	15	20	19	18	15
Total	612	627	552	566	589	537
(in minutes)	10.20	10.45	9.20	9.43	9.82	9.20
Manual Time (s)	383	398	323	337	360	307
(min)	6.38	6.63	5.38	5.62	6.00	5.38
Machine Time (s)	229	229	229	229	229	229
(min)	3.82	3.82	3.82	3.82	3.82	3.82

Demand (parts per hour)	10	People required	0.897
Takt time (minutes per part)	6	Excess Time (seconds)	-37
Cycle Time (minutes)	5.38		

5 Summary

A complete iteration of the product realization lifecycle has been completed. From defining the problem and establishing customer needs, a guidebook was established which the design team followed to develop design concepts. These were then evaluated based on how well they fulfilled certain functions that customers found important and a scoring system was developed to decide a best concept. During the architectural and parametric stages of the conceptual design process, various design decisions were made to synthesize a more visual and accurate representation of what would be produced, all while ensuring the best interest of the customer and saving the company the most time and money. Product features were designed, tested, and implemented into prototypes which were iterated multiple times to refine the design into a final prototype that was ready for production. During these prototype iterations, customer feedback was generated to further understand the needs of the customer and establish any improvements needed in the design. Each iteration also considered more precise specifications of the conceptual design process which culminated into the final prototype submitted for approval. Marketing and financial reviews were conducted to determine the best way to market the product to the intended customer base and also evaluated the profit margin per unit produced and sold. This analysis found that the final prototype generated about $2.97 of profit per unit, which would require about 1000 units to pay back the $3000 fixed costs accrued from research and development. Before this prototype was mass-produced, however, the process layout and design for manufacturing the product needed to be refined.

The layout of the factory floor used was fairly large, and the machines needed to complete the process were fairly spread out in the facility. This caused an excess in transport time which lengthened the cycle time required by the parts. Moving machines closer to one another and configuring the layout so that product could be made in a closed circuit loop allowed for 27 seconds to be saved just from product transport. Process improvements included modifying automated machine programs and tool paths, implementing more effective tooling, and addressing issues with quality and safety to mitigate the chances of machine breakdown, worker injury, or product defects. Another key implementation was the concept of one-piece flow, which prevented batching parts between stations. Once these were implemented, the final cycle time of the docking station product was found to be 5 minutes and 23 seconds, which was 37 seconds faster than the established takt time of 6 minutes per part.

Potential future research could include mitigating the amount of waste generated per unit manufactured. Due to the dimensions of the stock material ordered and the length-wise dimension of the pieces produced, only 36” of a 48” stock plank was able to be used. This equates to 25% waste for every unit produced, even before any major processing is done. Generally, the most acceptable waste per unit produced is under 10% so this is a definite point of improvement to be addressed in future study. Possible areas of focus could be on redesigning the product, or simply redesigning the tool path for the sheet router and waterjet so that more of the plank would be utilized and less would be wasted. Another alternative could include finding a different supplier that cut planks to a more optimal size for a comparable price.

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